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# SPACE TUG AVIONICS DEFINITION STUDY

FINAL REPORT

VOLUME II • AVIONICS FUNCTIONAL REQUIREMENTS

GENERAL DYNAMICS
*Convair Division*

# SPACE TUG AVIONICS DEFINITION STUDY

## FINAL REPORT

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# SPACE TUG AVIONICS DEFINITION STUDY

FINAL REPORT

VOLUME II • AVIONICS FUNCTIONAL REQUIREMENTS

April 1975

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Prepared for
National Aeronautics and Space Administration
GEORGE C. MARSHALL SPACE FLIGHT CENTER
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## FOREWORD

This final report on the Space Tug Avionics Definition Study was prepared by General Dynamics, Convair Division for the National Aeronautics and Space Administration's George C. Marshall Space Flight Center in accordance with Contract NAS8-31010. The study was conducted under the direction of NASA Contracting Officer Representative, Mr. James I. Newcomb, and deputy COR, Mr. Maurice Singley.

The study results were developed during the period from July 1974 to March 1975. The final presentation was made at NASA/MSFC on 3 April 1975. Principal Convair contributors to the study were:

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# SECTION 1

## SCOPE

This volume of the final report of the Space Tug Avionics Definition Study defines the requirements for the Tug Avionics system. The purpose of this volume is to provide the avionics system designer with a format that will enable him to: 1) understand all of the top level requirements of the Tug avionics system, 2) determine the requirements for all major subsystems/components of the avionics system, 3) modify the requirements as new/updated data becomes available, and 4) provide traceability so that the impact of any requirement change on the other levels of requirements can be quickly determined.

The approach shown in this volume is "top down," i.e., from mission to system to subsystem to component as follows: fifteen flight and ground operational phases of the Tug/Shuttle system are analyzed to determine the general avionics support functions that are needed during each of the mission phases and sub-phases. Each of these general support functions is then expanded into specific avionics system requirements, which are then allocated to the appropriate avionics subsystems.

This process is then repeated at the next lower level of detail where these subsystem requirements are allocated to each of the major components that comprise a subsystem.

This report follows a specification-type format and will permit an orderly evolution of Tug avionics requirements. As new data becomes available, this document can be easily updated; the general format can be used for Phase A and Phase B type studies and is easily expanded to include the detailed specifications needed for hardware procurement during Phase C/D. This volume contains only the top level requirements and their allocation to the major subsystems. Future studies and more detailed definition can be used to extend the requirements to the component level. Implementation requirements, verification/test requirements, and procurement specifications can be added as they become available.

This report updates the Avionics sections given in Applicable Document 2.

## SECTION 2

## APPLICABLE DOCUMENTS

The following documents comprise the sources for the avionics requirements of Section 3.

1. Request for Proposal No. DCN 8-1-4-21-00299, Marshall Space Flight Center, Exhibit A - Statement of Work.

2. Baseline Space Tug System Requirements & Guidelines, MSFC 68M00039-1, 15 July 1974, Marshall Space Flight Center.

3. Baseline Space Tug Configuration Definition, MSFC 68M00039-2, 15 July 1974, Marshall Space Flight Center.

4. Baseline Space Tug Flight Operations, MSFC 68M00039-3, 15 July 1974, Marshall Space Flight Center.

5. Baseline Space Tug Ground Operations: Verification, Analysis, and Processign, MSFC 68M00039-4, 15 July, 1974, Marshall Space Flight Center.

6. Space Shuttle System Payload Accommodations: JSC 07700, Vol. XIV, (Rev. C), 3 July 1974, Johnson Space Center.

7. Shuttle System Ground Operations Plan, K-SM-09, 18 December 1973, Kennedy Space Center.

8. Launch Site Accommodations Handbook for Shuttle Payload (Draft Copy), 1 February 1974, Kennedy Space Center.

9. Tug Operations and Payload Support Study, Vol. 3, Part 1 - Mission and Operations Analysis; SD73-SA-006-3, Contract NAS8-28876, Final Report, 5 March 1973.

10. Space Tug Systems Study (Cryogenic) Final Report, No. CASD-NAS73-033, January 1974, General Dynamics Convair Aerospace Division.

11. Tug Fleet and Ground Operations Schedules and Controls, Data Exchange Package, November 1974, Martin Marietta Corporation.

12. Space Tug Avionics Definition Study, Data Exchange Package, November 1974, General Dynamics Convair Division.

13. Space Tug/Shuttle Interface Compatibility Study, Data Exchange Package, November 1974, General Dynamics Convair Division.

14. OOS/Tug Orbital Operations and Mission Support, Data Exchange Package, November 1974, International Business Machines.

15. OOS/Tug Payload Requirements Compatibility, Data Exchange Package, November 1974, McDonnell Douglas Corporation.

16. Work Breakdown Structure and Dictionary for Space Tug Project, August 1974, General Dynamics Convair Division.

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# SECTION 3

# AVIONICS SYSTEM REQUIREMENTS

## 3.1 REQUIREMENTS ANALYSIS APPROACH

The avionics requirements that have been developed in this study, as well as those identified in the applicable documents, have been compiled in Section 3.2 of this volume. The compilation of these requirements was organized to accomplish two objectives: 1) to assure that all of the functional requirements are included, and 2) to provide traceability through the various levels of requirements that will eventually be compiled. Both of these objectives are satisfied using a top-down organizational approach as depicted in Figure 3-1.

The avionics functional requirements have their source in the events, tasks, or functions occurring during the mission and during the maintenance, refurbishment, and checkout operations on the ground. To assure completeness, every operational phase during the flight and ground operations of the Tug and all of the events and functions within those phases were used to establish the support required by the avionics system. Figure 3-1 shows this analysis, which resulted in 10 different categories of support functions required of the avionics system. (The actual avionics tasks associated with each phase are documented in Appendix A.)

The detailed functional requirements are grouped within their appropriate support function as shown in Figure 3-1. Each functional requirement is then allocated to one or more of the avionics subsystems, and the quantification of each functional requirement is listed according to the particular characteristics of that subsystem. This is the top level of functional requirements — those organized by support function — and is the only level documented in this report.

Lower level requirements can be developed from this approach. The next level establishes the functional requirements on a subsystem level by compiling those top level requirements (from all of the support functions) that were allocated to a particular subsystem. These subsystem requirements can then be allocated to the major elements or components of the subsystem and quantified with their particular characteristics. The next lower level of requirements becomes a component level and forms the basis for component procurement specification requirements.

This organizational approach provides the traceability of requirements from the operational phases and events to any level desired. Changes in requirements can be easily assessed as to their impact on other levels of requirements.

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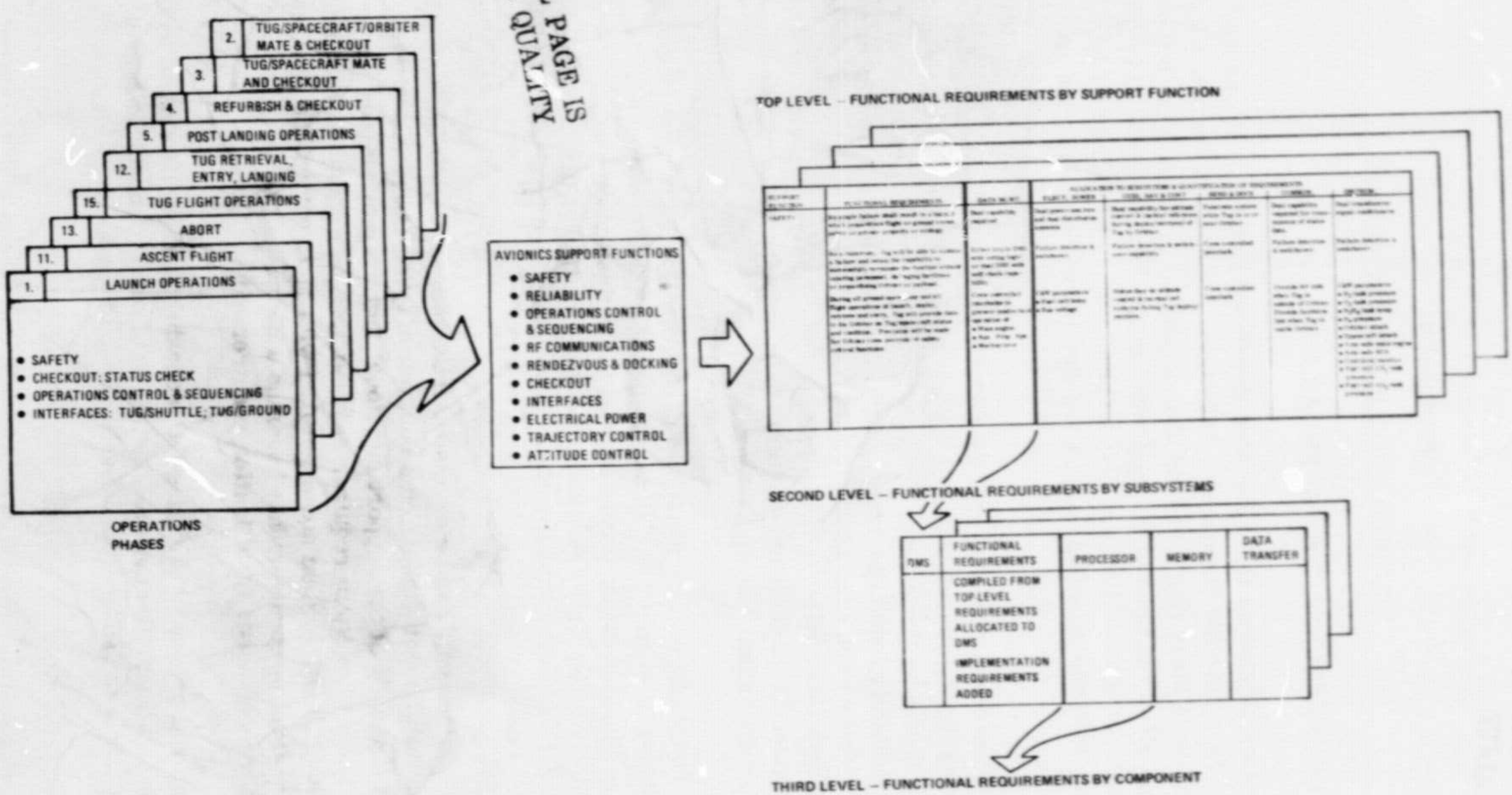


Figure 3-1. Requirements Organizational Approach

3.1.1 OPERATIONS CONCEPT. To assure that all of the avionics functional requirements have been included, it is necessary to identify all of the flight and ground operational phases. This section describes those phases and the tasks or events to be accomplished within each phase.

Figure 3-2 shows the 15 major phases of the normal flight/ground operations, aborted missions, mission control (ground), and DDTE/Production. The numbering system is a countdown from 5 (post landing from a completed mission) to 1 (launch operations). Six through 10 are DDTE/Production operations and are not included in the top level requirements of this report. Blocks 11, 12, 13, and 14 are associated with launch and entry phases of flight while the Tug is inside of the Orbiter. Block 15 shows the free flight phase of the Tug mission from release by the Orbiter to delivery of a spacecraft, to re-rendezvous of the Tug with the Orbiter prior to entry. Compiled in Table 3-1 is the second level breakdown of events occurring within each top level phase.

The ground operations functional flow becomes the description of: 1) the phases through which the Tug is processed in its turnaround cycle from landing on the mission just completed to its prelaunch readiness for the next flight, and 2) the tasks to be performed that will assure success in that processing. Any support that Tug avionics must provide in the conduct of these tasks becomes the source of part of the functional requirements for the Tug avionics system.

The same process accounts for the flight phases — all of the tasks or events are compiled that are necessary for the successful completion of the mission including special events such as the different conditions for abort. Any support Tug avionics must provide in the execution of these mission tasks becomes the source of all of the remaining functional requirements for the Tug avionics system.

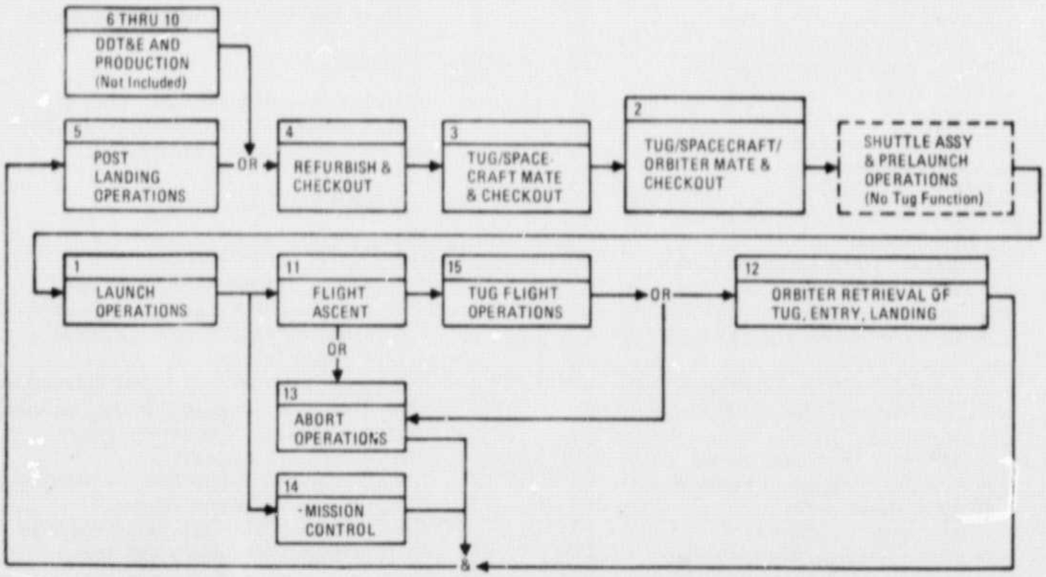


Figure 3-2. Space Tug Ground and Flight Operations — Top Level Flow Diagram

## Table 3-1. Tug Operational Phases — Second Level Breakdown

1. LAUNCH OPERATIONS
   - 1.1 Launch Readiness Verification & Countdown Prep.
   - 1.2 Load Propellants and Pressurants
   - 1.3 Backout/Payload Changeout
   - 1.3A Pad Abort
   - 1.4 Close Cargo Bay Doors, etc.
   - 1.5 Final Countdown

2. TUG/PAYLOAD/ORBITER MATE & C/O
   - 2.1 Install Tug/Payload in Orbiter at OPF
   - 2.2 Interface Verification
   - 2.3 Tug Monitoring

3. TUG/SPACECRAFT MATE & C/O
   - 3.1 Tug & Spacecraft Mate
   - 3.2 Load Tug Computer Flight Software
   - 3.3 Docking/Retrieval Simulation
   - 3.4 Functional Interface Test (FIT)
   - 3.5 Communication Verification
   - 3.6 Communication Verification
   - 3.7 Install Flight Battery
   - 3.8 Connect Ordnance
   - 3.9 Move to APS Propellant Loading Bay
   - 3.10 Partial Tug Pressurant Load
   - 3.11 Load APS Propellant
   - 3.12 Install Payload in Cannister
   - 3.13 Deliver Payload to Pad

4. REFURBISH & CHECKOUT
   - 4.1 Safe & Remove Unexpended Ordnance
   - 4.2 Drain & Purge APS
   - 4.3 Remove Flight Battery
   - 4.4 Leak Check Pressurant System
   - 4.5 Leak Check $LO_2$ Tank
   - 4.6 Leak Check $LH_2$ Tank
   - 4.7 Service Fuel Cells and Leak Check Reactant System
   - 4.8 Vent Remaining Pressurant
   - 4.9 Separate Tug from Adapter
   - 4.10 Tug Visual Damage Inspection
   - 4.11 Clean Tug & Prepare to Move
   - 4.12 Move into TPF Checkout Area
   - 4.13 Isolate Failed Hardware Causing Mission Anomalies
   - 4.14 Scheduled Tug Pre-Maintenance Tests
   - 4.15 Scheduled Tug Maintenance and Modification
   - 4.16 Adapter Visual Damage Inspection
   - 4.17 Clean & Prepare to Move Adapter
   - 4.18 Move Adapter into TPF C/O Area
   - 4.19 Isolate Adapter Hardware Causing Anomalies
   - 4.20 Scheduled Adapter Maintenance Tests
   - 4.21 Mate Tug with Adapter and Verify Interfaces
   - 4.22 Electrical Pre-Power Checks
   - 4.23 Mechanical Alignment Verification
   - 4.24 Apply Power to Tug
   - 4.25 Load PCM Data Format
   - 4.26 Calibrate Measurement System
   - 4.27 Mate Tug with Kick State
   - 4.28 Verify Interfaces
   - 4.29 Load & Verify Computer Software
   - 4.30 System Health Evaluation (SHE)
   - 4.31 Install Ordnance



5. POST LANDING OPERATION
   - 5.1 Safing and Purge
   - 5.1 Safing and Purge (RLTS)
   - 5.1 Safing and Purge (AOA/ATO)
   - 5.2 Remove Tug/Spacecraft

6., 7., 8., 9., 10. DDT&E/PRODUCTION (Not included in this report)

11. ASCENT FLIGHT
   - 11.1 Tug/SC Caution & Warning Monitor & Control
   - 11.2 Tug/SC Predeployment Operation and Checkout
   - 11.3 Rotate Tug/SC out of Payload Bay
   - 11.4 Perform Tug Final Activation and Status Check
   - 11.5 Attach RMS to Tug/Spacecraft
   - 11.6 Disconnect Umbilical & Adapter Latches
   - 11.7 Separate Tug Spacecraft from Orbiter
   - 11.8 Activate Tug ACS Thrusters

12. TUG RETRIEVAL, ENTRY, LANDING
   - 12.1 Transfer Tug/SC Control to Orbiter
   - 12.2 Command Tug to Preferred Orientation and Attitude
   - 12.3 Safe Tug for Docking & Perform Terminal Phase Final Maneuver
   - 12.4 Dock RMS to Tug
   - 12.5 Rotate Adapter & Activate Elements to Accept Tug
   - 12.6 Maneuver Tug/SC Adapter
   - 12.7 Remote Elec. Umbilical Panels
   - 12.8 Safe Tug/SC for Stowage
   - 12.9 Rotate Tug into Payload Bay & Secure
   - 12.10 Configure Tug/SC for Entry Flight
   - 12.11 Verify Tug/Status for Entry Flight
   - 12.12 Tug/SC C&W Monitor and Control

13. ABORT
   - 13.1 Propellant Dump Safing (RLTS)
   - 13.2 Propellant Dump/Safing (AOA/ATO)
   - 13.3 Verify Tug Safe for Retrieval

14. MISSION CONTROL

15. TUG FLIGHT OPERATIONS
   - 15.1 Phasing Orbit Injection & Coast
   - 15.2 Transfer Orbit Injection & Coast
   - 15.3 Payload Operational Orbit Injection
   - 15.4 Deploy Payload
   - 15.5 Inject into Payload Target Phasing Orbit
   - 15.6 Inject into Payload Target Rendezvous Orbit
   - 15.7 Rendezvous with Payload Target
   - 15.8 Dock with Payload
   - 15.9 Inject into Return Transfer Orbit/Coast
   - 15.10 Inject into Return Phasing
   - 15.11 Inject into Orbiter Rendezvous Orbit
   - 15.12 Orbiter Rendezvous with Tug

Therefore, the secondary level (and lower as they are developed) task definition within nine operational phases represents the complete source of all avionics (and other Tug systems) requirements.

3.1.2 AVIONICS SUPPORT OF OPERATIONS. The specific support that the Tug avionics system must provide in the conduct of the ground phases and in the execution of the flight phases was analyzed and are documented in the tables of Appendix A.

Table 3-2 is an example of this analysis showing the avionics support tasks during prelaunch operations. The mission phase is block number 1 in the top level functional flow diagram of Figure 3-2, and the second level events are the major tasks performed in this phase. The avionics tasks in support of the phase tasks are in summary form

Table 3-2. Avionics Tasks During Launch Operations

| MISSION PHASE | AVIONICS TASKS |
|---|---|
| 1.1 Launch Readiness Verification & Countdown Preparations | Provide instrumentation and data management capabilities to collect and display all needed data for all avionic, structural, mechanical, propulsion, and thermal subsystems. Collect and display data to payload/mission specialist stations and to appropriate ground monitor and control stations. Provide required software to interface with LPS. |
| 1.2 Load all Propellant & Pressurants into Tug | Provide instrumentation, data management and interface panels to monitor and control operations including all safety functions. Provide interface with LPS for prelaunch & countdown data display at appropriate ground control stations. Provide LPS interface software as required. |
| 1.3 Backout/Payload Changeout<br>Note: Payload changeout tasks and functional interface requirements are based on payload changeout occurring prior to attaining final two hour standby status and therefore, prior to propellant loading. The changeout room is in place with an environmental seal established between the room and Orbiter skin, and the payload bay doors are closed. | Provide instrumentation & data management capability to place Tug systems in safe condition, verify accomplishment, and display data on Orbiter mission/payload specialist panel and appropriate ground control panels. Includes providing all interface lines and panels to transmit data from Tug to Orbiter and ground locations. Provide required software input to LPS. Monitor safety critical functions. |
| 1.3A Pad Abort | Provide instrumentation and data management capability to successfully abort mission without violating safety requirements. Provide instrumentation and data management capability to monitor and control Tug propellant loading/termination operations and display required data at payload/mission specialist station and ground control stations. Includes interface panels at Orbiter mold line and aft bulkhead and all interconnecting lines. |
| 1.4 Close Cargo Bay Doors<br>Note: These are basically Orbiter tasks During these tasks the functional interfaces identified must be maintained, but are not associated with a discrete subtask. | Provide instrumentation, data management, interface panels (Orbiter aft bulkhead and mold line) and lines to monitor Tug status during this and other Orbiter pre-launch and standby activity. Provide interface with LPS for data display at appropriate ground control stations as well as caution and warning display at payload/mission specialist panel. Provide required interface software. |
| 1.5 Final Countdown | Provide instrumentation, data management, interface panels (Orbiter aft bulkhead and mold lines), and lines to monitor Tug status. Provide interface with LPS for prelaunch & countdown data display at the appropriate ground control station as well as caution and warning display at payload/mission specialist station. Provide required interface software. |

and range from providing information on safety-critical functions from special instrumentation to executing complete abort sequences.

3.1.3 SUPPORT FUNCTIONS. A summary of the kinds of functions for which the avionics system provides support is shown in Table 3-3. These general support functions (in the middle column) summarize the avionics tasks identified in each of the operational phases as compiled in the tables of Appendix A. Examination of the avionics tasks in Appendix A and as summarized in Table 3-3 shows that many of the avionics support tasks and functions recur throughout the different phases. In fact, the total of all of the avionics tasks is contained within 10 support function categories shown in the right-hand column of Table 3-3. These 10 support functions provide a convenient framework for collecting requirements at the top level without excessive repetition for each mission phase and sub-phase. Traceability is still maintained through Table 3-3 from the support functions back to the mission phase and detailed tasks of each phase by the tables in Appendix A.

## 3.2 AVIONICS FUNCTIONAL REQUIREMENT

The top level functional requirements for the Space Tug avionics system are compiled in Tables 3-4 through 3-15. They define characteristics and capabilities that the avionics system will have in order to support the tasks outlined for the execution of mission tasks and the conduct of ground operations. These requirements were: 1) compiled from a review of the applicable documents in Section 2, and 2) developed from the analyses conducted in this study. Functional requirements relate to supporting a particular task or function. Therefore, they are compiled under the support function to which they apply.

Each functional requirement is further allocated to the six avionics subsystems. The characteristics associated with each of the functional requirements are detailed under the applicable subsystem and represent the quantification of that requirement.

Requirements for the three interfaces of Tug/Orbiter, Tug/Payload, and Tug/Ground are arranged in a slightly different format. Quantification of the data being transmitted across the interface is shown in Tables 3-13, 3-14 and 3-15 for each of the mission phases/sub-phases. The data is categorized by "To Tug" and "From Tug." Collectively, these three tables quantify all of the Tug avionics system interfaces. Following each of the tables are footnotes explaining the source of the data and derivation of the values given.

## Table 3-3. Avionics Support Functions

| MISSION PHASE | AVIONICS SUPPORT FUNCTIONS PER MISSION PHASE |
|---|---|
| 5. POST LANDING OPERATIONS | • Safety<br>• Checkout: Status Check<br>• Interfaces: Tug/Ground; Tug Spacecraft; Tug/Shuttle |
| 4. REFURBISH & CHECKOUT | • Safety<br>• Checkout: Calibration, Initialization Functional Test<br>• Interface: Tug/Ground |
| 3. TUG/SPACECRAFT MATE AND CHECKOUT | • Safety<br>• Checkout: Status Checks<br>• RF Communication<br>• Interfaces: Tug/Spacecraft; Tug/Ground<br>• Operations Control & Sequencing |
| 2. TUG/SPACECRAFT/ORBITER MATE & CHECKOUT | • Safety<br>• Checkout: Status Check<br>• Operations Control & Sequencing<br>• Interfaces: Tug/Shuttle; Tug/Ground |
| 1. LAUNCH OPERATIONS | • Safety<br>• Checkout: Status Check<br>• Operations Control & Sequencing<br>• Interfaces: Tug/Shuttle; Tug/Ground |
| 11. ASCENT FLIGHT | • Safety<br>• Checkout: Status Check; Calibration; Initialization<br>• Operations Control & Sequencing<br>• RF Communications<br>• Attitude Control<br>• Electrical Power<br>• Interfaces: Tug/Shuttle; Tug/Spacecraft |
| 13. ABORT | • Safety<br>• Checkout: Status Check<br>• Operations Control & Sequencing<br>• Attitude Control<br>• RF Communications<br>• Interface: Tug/Shuttle; Tug/Spacecraft |
| 15. TUG FLIGHT OPERATIONS | • Trajectory Control: Navigation; Guidance; Flight Control<br>• Attitude Control: Coast; Maneuvering<br>• Operations Control & Sequencing<br>• RF Communications<br>• Rendezvous & Docking<br>• Safety<br>• Checkout: Status Check; Maintenance Support<br>• Interface: Tug/Spacecraft<br>• Electrical Power<br>• Reliability |
| 12. TUG RETRIEVAL, ENTRY, LANDING | • Safety<br>• Checkout: Status Check<br>• Attitude Control<br>• Operations Control & Sequencing<br>• RF Communications<br>• Interface: Tug/Spacecraft; Tug Shuttle |

AVIONICS SUPPORT FUNCTIONS

- SAFETY
- RELIABILITY
- OPERATIONS CONTROL & SEQUENCING
- RF COMMUNICATIONS
- RENDEZVOUS & DOCKING
- CHECKOUT
- INTERFACES
- ELECTRICAL POWER
- TRAJECTORY CONTROL
- ATTITUDE CONTROL

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## Table 3-4. Avionics Safety Requirements

| SUPPORT FUNCTION | FUNCTIONAL REQUIREMENTS | ALLOCATION TO SUBSYSTEMS & QUANTIFICATION OF REQUIREMENTS | | | | | |
|---|---|---|---|---|---|---|---|
| | | DATA MGMT. | ELECT. POWER | GUID, NAV & CONT | REND & DOCK | COMMUN. | INSTRUM. |
| SAFETY | No single failure shall result in a hazard which jeopardizes flight or ground crews, public or private property or ecology. | Dual capability required | Dual power sources and dual distribution systems | Dual capability for attitude control & inertial reference during deploy/retrieval of Tug by Orbiter. | Passivate system while Tug is in or near Orbiter | Dual capability required for transmission of status data. | Dual transducers/ signal conditioners |
| | As a minimum, Tug will be able to sustain a failure and retain the capability to successfully terminate the function without injuring personnel, damaging facilities or jeopardizing Orbiter or payload. | Either triple DMS with voting logic or dual DMS with self check capability. | Failure detection & switchover. | Failure detection & switchover capability | Crew controlled interlock. | Failure detection & switchover. | Failure detection & switchover. |
| | During all ground operations and all flight operations of launch, deploy, retrieve and entry, Tug will provide data to the Orbiter on Tug/spacecraft status and condition. Provision will be made for Orbiter crew override of safety critical functions. | Crew controlled interlocks to prevent inadvertent operation of:<br>• Main engine<br>• Aux. Prop. Sys.<br>• Mechanisms | C&W parameters<br>• Fuel cell temp<br>• Bus voltage | Status data on attitude control & inertial ref. systems during Tug deploy/ retrieve. | Crew controlled interlock | Provide RF link when Tug is outside of Orbiter. Provide hardwire link when Tug is inside Orbiter. | C&W parameters:<br>• $H_2$ tank pressure<br>• $O_2$ tank pressure<br>• $N_2H_4$ tank temp.<br>• $H_e$ pressure<br>• Orbiter attach<br>• Spacecraft attach<br>• Arm safe main engine<br>• Arm safe ACS<br>• Umbilical monitor<br>• Fuel cell $LH_2$ tank pressure<br>• Fuel cell $LO_2$ tank pressure |

## Table 3-5. Avionics Reliability Requirements

| SUPPORT FUNCTION | FUNCTIONAL REQUIREMENT | ALLOCATION TO SUBSYSTEMS | | | | | |
|---|---|---|---|---|---|---|---|
| | | DATA MGMT. | ELECT. POWER | GUID, NAV & CONT. | REND & DOCK | COMMUN. | INSTRUM. |
| RELIABILITY | Avionics System Reliability = 0.992. (This is avionics system apportionment to realize mission reliability of 0.97 - liftoff through landing.) | .99869 | .99945 | .99682 | .99985 | .99923 | .99794 |

## Table 3-6. Avionics Trajectory Control Requirements

| SUPPORT FUNCTION | FUNCTIONAL REQUIREMENTS | SUBSYSTEM NUMERICAL DATA: DATA MGMT. | ELECT. POWER | GUID, NAV & CONT. | REND & DOCK | COMMUN. | INSTRUM. |
|---|---|---|---|---|---|---|---|
| TRAJECTORY CONTROL | • Injection accuracy for spacecraft delivery to geosynchronous orbit will be:<br>Position 3σ 50 KM<br>Velocity 3σ 10 M/S<br>• Injection accuracy for spacecraft delivery to earth orbits of low/medium altitude will be:<br>Position 3σ 10 KM<br>Velocity 3σ 10 M/S<br>• Injection accuracy for spacecraft delivery to planetary orbits will be TBD.<br>• During retrieval of Tug by Orbiter, Tug return envelope will be:<br>Altitude Nominal ±15 n. mi. (27.8 Km)<br>Velocity Nominal ±85 fps (25.7 mps)<br>Inclination Nominal 20.15°<br>Range 250 ± 44 n. mi. (263 ± 82 Km) | | | Axis Misalignment 144 arc sec<br>Accelerometer Bias 100 μg<br>Accelerometer Scale Factor 60 PPM<br>Gyro Fixed Drift 0.1 deg/hr<br>Cyro Scale Factor 55 PPM | | | |
| | • For geosynchronous missions, 3σ capability of navigation update system will be: | | | Position 4.2 n. mi. (7.8 KM)<br>Velocity 11.3 fps (3.5 mps<br>Time 3 hrs. before apogee burn<br>Attitude .64° at 15 mins. before apogee burn | | | |
| | • Pointing accuracy handoff | | | Attitude 0.2°<br>Rate 0.1°/sec | | | |

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Table 3-7. Avionics Electrical Power Requirements

| SUPPORT FUNCTION | FUNCTIONAL REQUIREMENTS | SUBSYSTEM NUMERICAL DATA: DATA MGMT. | ELECT. POWER | GUID, NAV. & CONT. | REND & DOCK | COMMUN. | INSTRUM. |
|---|---|---|---|---|---|---|---|
| ELECTRICAL POWER | •Power Profile | | See Table | | | NOTE: Power Quality will be dictated by requirements of other subsystems. Data to be added when available. | |
| | •Steady state voltage | | 28 VDC +4.5 -4.0 | | | | |
| | •Regulation (measured at using hardware) | | | | | | |
| | •Voltage drop between source & using hardware under maximum steady state power consumption. | | 1.0 VDC | | | | |
| | •Power source voltage - Normal | | 28 VDC Nominal | | | | |
| | •Power source voltage - Maximum | | <32.5 VDC @ 800 watts | | | | |
| | •Power source voltage - Minimum | | >25 VDC @ 3,500 watts | | | | |
| | •Primary power source - power level | | 800-2000 watts with 8 hr peaking at 3,500 watts | | | | |
| | •Primary power source, total energy (max.) | | 285 KWH for 185 hr mission | | | | |
| | •Emergency battery voltage | | 28 VDC | | | | |
| | •Emergency battery peak power | | 1,500 watts | | | | |
| | •Emergency battery capacity | | 23 ampere hr | | | | |
| | •For safety and reliability, the primary source shall be dual redundant with an additional emergency battery as a backup source while the the Tug is within 3000 ft of the Orbiter. In the event of any single failure in the primary power source, it shall fail operationally. The primary source shall continue to produce power as specified. In the event of multiple failures in the primary power source, the primary power source shall shutdown in a safe mode. The emergency battery will automatically switch on to supply Tug and payload power until Orbiter crew overrides. In the event that primary source power failure and shutdown occurs immediately after the Tug has been deployed, or in the terminal stages of retrieval, the emergency battery shall be automatically switched on to provide Tug power. The power distribution and control will be dual redundant, with a third separate hardwire emergency system for Orbiter crew override. | | | | | | |

| | ASCENT | PREDEPLOY C/O | DEPLOY TUG | ON-ORBIT PL C/O | COAST | ENG BURN | GUID UPDATE | R&D | RETRIEVAL | | DESCENT | RTLS ABORT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | NORMAL | EMERG | | |
| AVIONICS | | | | | | | | | | | | |
| DATA MGT | 107 | 107 | 107 | 107 | 107 | 107 | 107 | 107 | 107 | 107 | 107 | 107 |
| GN&C | - | 392 | 392 | 392 | 392 | 392 | 392 | 392 | 392 | 350 | - | - |
| R&D | - | 50 | - | - | - | - | - | 50 | - | - | - | - |
| COMMUNICATIONS | 10 | 10 | 193 | 193 | 193 | 193 | 193 | 193 | 193 | 193 | 10 | 10 |
| INSTRUMENTATION | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| POWER SYS | 115 | 140 | 130 | 130 | 130 | 140 | 130 | 140 | 130 | 40 | 115 | 115 |
| AVG HEATERS* | 30 | 230 | 37 | 14 | 21 | 17 | 9 | 41 | 14 | [illegible] | 4 | 30 |
| AVIONICS TOTAL | (312) | (979) | (909) | (886) | (893) | (899) | (881) | (973) | (886) | (748) | (286) | (312) |
| OTHER TUG REQUIREMENTS | | | | | | | | | | | | |
| MAIN ENG CIR PUMPS | - | 40 | 40 | 40 | 40 | - | 40 | 40 | 40 | [illegible] | 40 | 40 |
| CONTROL V'S & "O" & VENT | 225 | 256 | 281 | 225 | 201 | 526 | 218 | 261 | 281 | 174 | 364 | 728 |
| APS MOTOR HEATERS | - | - | - | - | 64 | 50 | 30 | 50 | 50 | [illegible] | - | - |
| OTHER SYS TOTALS | (225) | (296) | (321) | (265) | (305) | [illegible] | [illegible] | (351) | (371) | [illegible] | (404) | (768) |
| TOTAL TUG REQUIREMENTS | 537 | 1,275 | 1,230 | 1,151 | 1,198 | 1,485 | 1,169 | 1,324 | 1,257 | 865 | 690 | 1,080 |
| SINGLE PL REQUIREMENTS ** | 600 | 650 | 700 | 700 | 200 | 200 | 200 | - | - | - | - | - |
| TUG POWER REQUIREMENT | 1,137 | 1,925 | 1,930 | 1,851 | 1,398 | 1,685 | 1,369 | 1,324 | 1,257 | 865 | 690 | 1,080 |

*HEATER DATA FROM NASB 29670 SPACE TUG THERMAL CONTROL, AS MODIFIED TO REFLECT EQUIPMENT
**SINGLE PL POWER REQ FROM MDAC (11/22/74)

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## Table 3-8. Avionics Attitude Control Requirements

| SUPPORT FUNCTION | FUNCTIONAL REQUIREMENTS | ALLOCATION TO AVIONICS SUBSYSTEMS & QUANTIFICATION: DATA MGMT. | ELECT. POWER | GUID, NAV & CONT. | REND & DOCK | COMMUN. | INSTRUM. |
|---|---|---|---|---|---|---|---|
| ATTITUDE CONTROL | The Tug shall be capable of deploying spacecraft in a stable mode with velocity, attitude rate, and attitude accuracies (relative to inertial space) of: | | | Translation velocity a safe positive to 5.0 ft/sec.<br>Attitude rates ±0.10 deg./sec. (all axes)<br>Attitude ±0.20 deg. (all axes) | | | |
| | During retrieval of Tug by the Orbiter, the Tug shall have the capability to maintain station keeping accuracies of: | | | Longitudinal Velocity 0.1 to 1.0 ft/sec (.03 to .3 m/s<br>Lateral Velocity 0.5 ft/sec (.6 m/s)<br>Angular Misalignment ±10 deg.<br>Angular Rate 1.0 deg/sec | | | |
| | The Tug shall be capable of providing any orientation or attitude required by the spacecraft during Tug/spacecraft mission operations except as limited by main engine burns and navigation updates. | | | | | All attitude antenna pointing capability | |
| | Tug shall have capability to provide short term pointing to spacecraft - prior to release. | | | ±0.2° of required spacecraft attitude | | | |
| | Tug shall have capability to hold angular rate and attitude position. | | | Mode / Attitude / Rate<br>Coarse 3σ 5° 3σ 1°/sec<br>Fine 3σ 0.5° 3σ 0.1°/sec | | | |

## Table 3-9. Avionics Communications Requirements

| SUPPORT FUNCTION | FUNCTIONAL REQUIREMENTS | ALLOCATION TO AVIONICS SUBSYSTEM & QUANTIFICATION: DATA MGMT. | ELECT. POWER | GUID. NAV. & CONTROL | REND & DOCKING | COMMUNICATION | | INSTRUM. |
|---|---|---|---|---|---|---|---|---|
| COMMUNICATION | The Tug shall be compatible with the NASA STDN/TDRS and the AF SGLS/SCF communications and tracking systems | | | | | Forward Link | Return Link | |
| | RF | | | | | STDN 2025 - 2100 | 2200 - 2250 | |
| | | | | | | TDRS 2028. 1354 to 2115. 6154 MHz | 2202. 500 to 2297. 500 MHz | |
| | | | | | | AFSCF 1763. 721 to 1839. 795 MHz | 2202. 500 to 2297. 500 MHz | |
| | Modulation | | | | | STDN AM/PSK/PM<br>70 KHz SCO | PCM/PSK/PM<br>1. 024 MHz SCO | |
| | | | | | | TDRS TDM/PSK<br>Spread Spectrum | PCM/PSK<br>Direct | |
| | | | | | | AFSCF AM/PSK/PM | 1. 024 MHz SCO | |
| | $EIRP_{max}$ | | | | | 23 dbw | | |
| | Bit Rates | | | | | TELEMETRY | | |
| | | | | | | Tug Engr Data | 16 KBPS | |
| | | | | | | Spacecraft Data | 10 KBPS | |
| | | | | | | Encoded Data | 64 KBPS | |
| | | | | | | High Rate Data | 256 KBPS | |
| | | | | | | COMMAND | | |
| | | | | | | NASA | 2 KBPS | |
| | | | | | | DOD | 2 K BAUD | |
| | RF communication capability shall be available between the Orbiter and the Tug for command and control functions while separated from the Orbiter | | | | | | | |
| | $EIRP_{min}$ | | | | | 3 dbw | | |
| | Coverage | | | | | Omni receive/transmit near Orbiter | | |
| | Tug critical command & control circuitry shall be designed to be fail operational as a minimum | | | | | Dual Redundant Components | | |
| | The Tug shall be capable of receiving secure commands from & transmitting secure data to the Orbiter & Tug/spacecraft operations center(s). | | | | | Command Decrypter KGR29<br>Data Encrypter KGT- | | |

## Table 3-10. Avionics Checkout Requirements

| SUPPORT FUNCTION | FUNCTIONAL REQUIREMENTS | ALLOCATION TO SUBSYSTEMS AND QUANTIFICATION | | | | | |
|---|---|---|---|---|---|---|---|
| | | DATA MGMT. | ELECT. POWER | GUID, NAV & CONT | REND & DOCK | COMMUN. | INSTRUM. |
| CHECKOUT | Implement philosophy of "conditioned" monitored maintenance with preflight checks" ($CMM_{PF}$). Support safety/ mission reliability/refurbishment/cost goals of Tug Program. | ← APPLICABLE TO ALL SUBSYSTEMS → | | | | | |
| | Provide safety peculiar status data to ensure that safety goals for flight and ground crews are met. | Provide primary software routines in Tug. Interface with backup routines on Orbiter & ground. Provide 1.5K software words to implement abort/ safety commands from Orbiter. | | | | Provide hardware or RF link to implement safety commands across interfaces. | 11 special redundant transducers monitoring these functions:<br>$H_2$ tank pressure<br>$O_2$ tank pressure<br>$N_2H_4$ tank temp.<br>$H_e$ pressure<br>Orbiter attachment<br>Spacecraft attachment<br>Arm safe main engine<br>Arm/safe ACS<br>Umbilical monitor<br>Fuel cell $LO_2$ tank press.<br>Fuel cell $LO_2$ tank press. |
| | Provide status data of Tug systems in support of ground & flight operations. Provide readiness data during pre-launch operations to support "commit to launch" decisions. Provide readiness data during on-orbit operations to support "commit to mission" decisions. | Maximum utility of status software in support of redundancy management. Total software = 6.2 K words. Format into [illegible] bits for downlink or store on tape. Provide two downlink formats. | Monitor internal redundancy status. Provide internal monitors. | Monitor & process functional outputs for limit detection. Interrogate & process limited BITE. Provide Internal monitors. | Monitor & process functional outputs for limit detection. Interrogate & process limited BITE. Provide internal monitors. | Monitor & process functional outputs for limit detection. Provide internal monitors. | 48 Transducers<br>198 Special purpose internal monitors (87 redundant) |
| | Provide initialization on selected Tug systems/subsystems. Provide cycling in operational modes as required. | Reset DIUs. Load flight program. Store & execute initialization state vectors. | Lockout improper power application sequences. | | | | |
| | | ← POWER UP ROUTINES, TURN ON SEQUENCES, PRE CONDITION REGISTERS → | | | | | |
| | Perform calibration of selected subsystems. Determine compensating parameters to ensure compliance with performance specs. Load updated parameters into DMS. | Buffer LPS controlled calibration routines. Load & execute selected calibration software modules under DMS preflight executive. | | Mechanically align guidance subsystem. Calibrate. Tune inertial components. | Align sensors. Calibrate. | | Monitor analog/ digital converter self calibration. |

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## Table 3-10. Avionics Checkout Requirements, Contd

| SUPPORT FUNCTION | FUNCTIONAL REQUIREMENTS | ALLOCATION TO SUBSYSTEMS AND QUANTIFICATION: DATA MGMT. | ELECT. POWER | GUID, NAV & CONT. | REND & DOCK | COMMUN. | INSTRUM. |
|---|---|---|---|---|---|---|---|
| CHECKOUT | Perform functional tests on all Tug systems. Prior to mating with spacecraft, provide input data to LRUs, measure response and determine tolerances. Provide go/no go status. | Load & execute LPS uplinked functional test routines and/or modules under DMS preflight executive control. During flight allocate 1K of temporary memory. Execute safety sequence commands to verify functional integrity. | | Provide target. | Provide target. | Establish & verify RF link prior to disconnect of umbilical & release of Tug by Orbiter. Accept software uplink @ 2K bits. | Verify functional integrity of safety peculiar instrumentation. |
| | Gather in-flight data in support of $CMM_{PF}$ concept. Store data onboard Tug or transmit to ground. Use passive detectors when possible. | Buffer & format data into 256K downlink. Provide mass storage capability of $10^8$ bits. | PROVIDE 42 ADDITIONAL INTERNAL MONITORS | | | ≥ 160K bit RF downlink | Special purpose for maintenance only: 147 active transducers 200 passive transducers 42 special purpose internal monitors |

## Table 3-11. Avionics Operations Sequencing and Control Requirements

| SUPPORT FUNCTION | FUNCTIONAL REQUIREMENTS | ALLOCATION TO AVIONICS SUBSYSTEMS: DATA MGMT. | ELECT. PWR. | GUID, NAV & CONT | REND & DOCK | COMMUN. | INSTRUM. |
|---|---|---|---|---|---|---|---|
| OPERATIONS SEQUENCING & CONTROL | Provide all discrete commands in support of vehicle operations throughout mission. | Estimated software:<br>Sequencing 1816<br>Tank Pressure Control 794<br>Phased Array Control 200<br>Total 2830 words | | | | | |

## Table 3-12. Avionics Rendezvous and Docking Requirements

| SUPPORT FUNCTION | FUNCTIONAL REQUIREMENTS | ALLOCATION TO AVIONICS SUBSYSTEMS & QUANTIFICATION | | | | | |
|---|---|---|---|---|---|---|---|
| | | DATA MGMT. | ELECT. POWER | GUID. NAV. & CONTROL | RENDEZVOUS & DOCKING | COMMUN. | INSTRUM. |
| RENDEZVOUS AND DOCKING | The Tug will be capable of providing the following types of services to spacecraft that are Tug/Shuttle compatible:<br>• Retrieval of Spacecraft & return to earth<br>• On orbit servicing<br>• Inspection | ← GENERAL APPLICABILITY → | | | Tug is active element | | |
| | Rendezvous Requirements:<br>• Spacecraft position<br>• Spacecraft attitude rate<br>• Tug injection accuracies | | | | Known to with 1.0 n. mi. (1.85 Km) Spherical radius, 3 sigma<br>Controlled within 1°/sec all axes.<br>Position 4.2 n. mi. (2.8 Km) Velocity 11.3 fps (3.5 mps) | | |
| | Inspection requirements following spacecraft deployment | | | | Ensure spacecraft mission preparations are adequate | | |
| | Docking Requirements<br>• Docking mechanism shall be designed for the following misalignments<br>Radial<br>Angular<br>Axial<br>Transverse<br>Angular Rate<br>• Spin/Despin Device | | | | 1.0 ft (0.3 m)<br>5°<br>0.1 to 1.0 fps (0.03 to 0.3 m/s)<br>0.3 fps (0.09 m/s)<br>0.5°/sec<br>Make provisions for accepting a device with spin rates up to 100 RPM | | |
| | Retrieval Requirements<br>• Safety/mission reliability | | | | • Confirm that all spacecraft systems & interfaces are Tug/Shuttle compatible (Prior to completion of retrieval operations and prior to retrieval of Tug/spacecraft by Orbiter)<br>• Provide remote/emergency jettisoning of spacecraft appendages. | | |

## FOOTNOTES TO TABLE 3-13

1. Power changeover is accomplished during the final countdown from ground supplied power. Ref. Table 16.

2. To completely checkout the vehicle during verification and countdown preps, several programs will be loaded into the Tug accounting for 15,000 words of uplink. During the remainder of the launch operations 10% of maximum uplink data is used.

3. An 8-bit data word size (byte) is chosen for both uplink and downlink word sizes because this is the standard interface word size for most state-of-the-art computers.

4. A high rate word uplink rate of 400 words per second is chosen to allow the loading of an 800 word program in 2 seconds. This rate will allow reasonable machine response time for most test sequences.

5. The number of 8-bit words is derived as follows:

   Line replaceable units × average system redundancy × 16-bit signals per LRU × conversion to 8-bit words + basic telemetry list = total downlink list. 40 × 2 × 2 × 2 + 130 = 450 8-bit words

   All signals are interrogated during the loading of propellants and pressurants since the changing of the vehicle environment from ambient to cryogenic conditions stresses the avionics more than any other prelaunch activity.

6. The word rate of 1800 words is derived as follows:

   | | |
   |---|---|
   | High rate avionics 320 LRU signals × 20% sampling rate × 20 Hz = | 1280 |
   | Low rate avionics 320 LRU signals × 80% sampling rate × 1 Hz = | 256 |
   | TLM 130 basic rate × 2 Hz | 260 |
   | Total 8-bit words/sec | 1796 |

   As stated in (5) when all signals are interrogated the highest rates are required during prelaunch propellant loadings.

7. During 2.2 all interface wires are to be "rung-out".

8. This number of words is chosen to sufficiently verify the uplink.

9. The highest operating uplink rate is chosen to verify the uplink (other than computer main memory loading).

10. During 2.2 all interface wires are to be "rung-out".

11. This number of words is chosen to sufficiently checkout the downlink.

12. The highest operating downlink rate is chosen to verify the downlink (other than computer main memory loading).

13. Control safing override operations from the Shuttle.

14. All safety and other commands will be through the digital uplink.

15. Maintain an uplink rate to allow responsive control of venting and dumping valves.

16. Safety functions are monitored independent of the digital downlink to assure crew safety in the occurrance of a digital failure.

17. The number of 25 8-bit words is derived as follows:

   6 Subsystems × 2 words per subsystem × 2 average system redundancy = 24 8-bit words for downlink

18. The low rate word rate is derived from 8-bit words × sampling rate × Hz

   | | |
   |---|---|
   | 24 × 20% × 20 | 100 |
   | 24 × 80% × 1 | 20 |
   | Total low rate downlink 8-bit words/sec | 120 |

19. The power value represents the sum of the worst case power consumed during any part of the ascent phase.

20. These commands represent the release sequence from the Shuttle.

21. The rate of 400 words per second is required to satisfy the Tug navigation update. The update is as follows:

   a. Time sync to 1 millisecond accuracy covering 24 hours of time span (48 bits).
   b. Three by three (9 words) matrix of 18-bit velocity update.

22. Same as footnote 10.

23. Same as footnote 11.

24. A medium rate of 800 words per second downlink is used for medium Tug activity and is defined as the mid-point between the high and low downlink rates (see footnotes 6 and 18).

25. During Tug retrieval, entry, landing and abort the power consumption is low since the GN&C, propulsion system and electrical power system is off.

Table 3-13. Avionics Tug/Orbiter Interface Requirements

| INTERFACE / MISSION PHASE | TO TUG | | | | | FROM TUG | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | POWER +28V | SAFETY DISCRETE COMMANDS | DIGITAL COMMAND | | | DISCRETE COMMAND | SAFETY FUNCTION TO BE MONITORED | STATUS MONITOR DOWNLINK | | | DIGITAL COMMAND | | |
| | WATTS | NO. OF CMDS | WORDS | BITS WORD | WORDS SEC | NO. OF CMDS | NO. OF CMDS | WORDS | BITS WORD | WORDS SEC | WORDS | BITS WORD | WORDS SEC |
| **1. LAUNCH OPERATIONS** | | | | | | | | | | | | | |
| 1.1 Launch Readiness Verification & Countdown Prep. | 0 | 0 | 15000 | 8 | 400 | N/A | 0 | 400 | 8 | 800 | N/A | N/A | N/A |
| 1.2 Load Propellants & Pressurants | 0 | 0 | 1500 | 8 | 40 | | 0 | 450 | 8 | 1800 | N/A | N/A | N/A |
| 1.3 Backout/Payload Changeout | 0 | 0 | 1500 | 8 | 40 | | 0 | 450 | 8 | 1800 | N/A | N/A | N/A |
| 1.3A Pad Abort | 0 | 0 | 1500 | 8 | 40 | | 0 | 450 | 8 | 1800 | N/A | N/A | N/A |
| 1.4 Close Cargo Bay Doors, etc. | 0 | 0 | 1500 | 8 | 40 | | 0 | 450 | 8 | 1800 | N/A | N/A | N/A |
| 1.5 Final Countdown | 537 [1] | 0 | 1500 [2] | 8 [3] | 40 [4] | N/A | 0 | 450 [5] | 8 [3] | 1800 [6] | N/A | N/A | N/A |
| **2. TUG/PAYLOAD/ORBITER MATE & C/O** | | | | | | | | | | | | | |
| 2.1 Install Tug/P/L in Orbiter at OPF | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.2 Interface Verification | 0 | 9 | 100 | 8 | 400 | | 11 | 25 | 8 | 1800 | 0 | 0 | 0 |
| 2.3 Tug Monitoring | 0 | 0 [7] | 0 [8] | 0 [3] | 0 [9] | | 11 [10] | 25 [11] | 8 [3] | 175 [12] | ? | 0 | 0 |
| **3. TUG/SPACECRAFT MATE & C/O** | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 3.1 Tug & Spacecraft Mate | | | | | | | | | | | | | |
| 3.2 Load Tug Computer Flt. Software | | | | | | | | | | | | | |
| 3.3 Docking/Retrieval Simulation | | | | | | | | | | | | | |
| 3.4 Functional Interface Test (FIT) | | | | | | | | | | | | | |
| 3.5 Communication Verification | | | | | | | | | | | | | |
| 3.6 Communication Verification | | | | | | | | | | | | | |
| 3.7 Install Flight Battery | | | | | | | | | | | | | |
| 3.8 Connect Ordnance | | | | | | | | | | | | | |
| 3.9 Move to APS Prop. Loading Bay | | | | | | | | | | | | | |
| 3.10 Partial Tug Pressurant Load | | | | | | | | | | | | | |
| 3.11 Load APS Propellant | | | | | | | | | | | | | |
| 3.12 Install Payload in Cannister | | | | | | | | | | | | | |
| 3.13 Deliver Payload to Pad | | | | | | | | | | | | | |
| **4. REFURBISH & CHECKOUT** | | | | | | | | | | | | | |
| 4.1 Safe & Remove Unexpended Ordnance | | | | | | | | | | | | | |
| 4.2 Drain & Purge APS | | | | | | | | | | | | | |
| 4.3 Remove Flight Battery | | | | | | | | | | | | | |
| 4.4 Leak Check Pressurant System | | | | | | | | | | | | | |
| 4.5 Leak Check $LO_2$ Tank | | | | | | | | | | | | | |
| 4.6 Leak Check $LH_2$ Tank | | | | | | | | | | | | | |
| 4.7 Service Fuel Cells & Leak Check Reactant System | | | | | | | | | | | | | |
| 4.8 Vent Remaining Pressurant | | | | | | | | | | | | | |
| 4.9 Separate Tug From Adapter | | | | | | | | | | | | | |
| 4.10 Tug Visual Damage Inspection | | | | | | | | | | | | | |
| 4.11 Clean Tug & Prepare to Move | | | | | | | | | | | | | |
| 4.12 Move into TPF Checkout Area | | | | | | | | | | | | | |
| 4.13 Isolate Failed Hardware Causing | | | | | | | | | | | | | |

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| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.5 Tug Monitoring | | | | | | | | | | | | | |
| **3. TUG/SPACECRAFT MATE & C/O** | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 3.1 Tug & Spacecraft Mate | | | | | | | | | | | | | |
| 3.2 Load Tug Computer Flt. Software | | | | | | | | | | | | | |
| 3.3 Docking Retrieval Simulation | | | | | | | | | | | | | |
| 3.4 Functional Interface Test (FIT) | | | | | | | | | | | | | |
| 3.5 Communication Verification | | | | | | | | | | | | | |
| 3.6 Communication Verification | | | | | | | | | | | | | |
| 3.7 Install Flight Battery | | | | | | | | | | | | | |
| 3.8 Connect Ordnance | | | | | | | | | | | | | |
| 3.9 Move to APS Prop. Loading Bay | | | | | | | | | | | | | |
| 3.10 Partial Tug Pressurant Load | | | | | | | | | | | | | |
| 3.11 Load APS Propellant | | | | | | | | | | | | | |
| 3.12 Install Payload in Cannister | | | | | | | | | | | | | |
| 3.13 Deliver Payload to Pad | | | | | | | | | | | | | |
| **4. REFURBISH & CHECKOUT** | | | | | | | | | | | | | |
| 4.1 Safe & Remove Unexpended Ordnance | | | | | | | | | | | | | |
| 4.2 Drain & Purge APS | | | | | | | | | | | | | |
| 4.3 Remove Flight Battery | | | | | | | | | | | | | |
| 4.4 Leak Check Pressurant System | | | | | | | | | | | | | |
| 4.5 Leak Check $LO_2$ Tank | | | | | | | | | | | | | |
| 4.6 Leak Check $LH_2$ Tank | | | | | | | | | | | | | |
| 4.7 Service Fuel Cells & Leak Check Reactant System | | | | | | | | | | | | | |
| 4.8 Vent Remaining Pressurant | | | | | | | | | | | | | |
| 4.9 Separate Tug From Adapter | | | | | | | | | | | | | |
| 4.10 Tug Visual Damage Inspection | | | | | | | | | | | | | |
| 4.11 Clean Tug & Prepare to Move | | | | | | | | | | | | | |
| 4.12 Move into TPF Checkout Area | | | | | | | | | | | | | |
| 4.13 Isolate Failed Hardware Causing Mission Anomalies | | | | | | | | | | | | | |
| 4.14 Scheduled Tug Pre-Main. Tests | | | | | | | | | | | | | |
| 4.15 Sch. Tug Main. & Modification | | | | | | | | | | | | | |
| 4.16 Adapter Visual Damage Inspection | | | | | | | | | | | | | |
| 4.17 Clean & Prepare to Move Adapter | | | | | | | | | | | | | |
| 4.18 Move Adapter into TPF C/O Area | | | | | | | | | | | | | |
| 4.19 Isolate Adpt Hardware Causing Anomalies | | | | | | | | | | | | | |
| 4.20 Scheduled Adapter Main. Tests | | | | | | | | | | | | | |
| 4.21 Mate Tug with Adapter & Verify Interfaces | | | | | | | | | | | | | |
| 4.22 Electrical Pre-Power Checks | | | | | | | | | | | | | |
| 4.23 Mechanical Alignment Verification | | | | | | | | | | | | | |
| 4.24 Apply Power To Tug | | | | | | | | | | | | | |
| 4.25 Load PCM Data Format | | | | | | | | | | | | | |
| 4.26 Calibrate Measurement System | | | | | | | | | | | | | |
| 4.27 Mate Tug with Kick Stage | | | | | | | | | | | | | |
| 4.28 Verify Interfaces | | | | | | | | | | | | | |
| 4.29 Load & Verify Computer Software | | | | | | | | | | | | | |
| 4.30 System Health Evaluation (SHE) | | | | | | | | | | | | | |
| 4.31 Install Ordnance | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| **5. POST LANDING OPERATION** | | | | | | | | | | | N/A | N/A | N/A |
| 5.1 Safing and Purge | 0 | 9 | 50 | 8 | 40 | | 11 | 25 | 8 | 120 | | | |
| 5.1 Safing and Purge (RLTS) | 0 | 9 | 75 | 8 | 40 | | 11 | 25 | 8 | 120 | | | |
| 5.1 Safing and Purge (AOA/ATO) | 0 | 9 | 75 | 8 | 40 | | 11 | 25 | 8 | 120 | | | |
| 5.2 Remove Tug/Spacecraft | 0 | 0 [13] | 0 [14] | 0 [3] | 0 [15] | | 0 [16] | 0 [17] | 0 [3] | 0 [illegible] | | | |
| 6., 8., & 10 7., 9., (DDT&E/Production Not included in this report) | | N/A | N/A | N/A | N/A | | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| **11. ASCENT FLIGHT** | | | | | | | | | | | | | |
| 11.1 Tug/SC Caution & Warning Monitor & Control | 537 | 0 | 0 | 0 | 0 | | 11 | 25 | 8 | 120 | | | |
| 11.2 Tug/SC Predeploy Operation & C/O | 1275 | 0 | 20 | 8 | 400 | | 11 | 400 | 8 | 1800 | | | |
| 11.3 Rotate Tug/SC out of Payload Bay | | 0 | 20 | 8 | 400 | | 11 | 400 | 8 | 800 | | | |
| 11.4 Perform Tug Final Activation & | | 0 | 0 | 0 | 0 | | 11 | 400 | 8 | 800 | | | |
| Status Check | | 0 | 0 | 0 | 0 | | 11 | 400 | 8 | 800 | | | |
| 11.5 Attach RMS to Tug/Spacecraft | 1275 | 0 | 0 | 0 | 0 | | 11 | 400 | 8 | 800 | | | |
| 11.6 Disconnect Umb. & Adapter Latches | 1230 | 0 | 0 | 0 | 0 | | 11 | 400 | 8 | 800 | | | |
| 11.7 Separate Tug Spacraft from Orbiter | | 0 | 0 | 0 | 0 | | 0 | 400 | 8 | 800 | | | |
| 11.8 Activate Tug ACS Thrusters | 1230 [19] | 0 | 10 [illegible] | 8 [3] | 400 [illegible] | | 0 [22] | 400 [23] | 8 [3] | 800 [21] | | | |
| **12. TUG RETRIEVAL, ENTRY, LANDING** | | | | | | | | | | | | | |
| 12.1 Transfer Tug/SC Control to Orbiter | 0 | 0 | 0 | 0 | 0 | | 0 | 25 | 8 | 120 | | | |
| 12.2 Command Tug to Preferred Orientation & Attitude | 0 | 0 | 1 | 8 | 40 | | 0 | 23 | 8 | 120 | | | |
| 12.3 Safe Tug for Docking & Perform Terminal Phase Final Maneuver | 0 | 0 | 1 | 8 | 40 | | 0 | 400 | 8 | 800 | | | |
| 12.4 Dock RMS to Tug | 0 | 0 | 1 | 8 | 40 | | 0 | 400 | 8 | 800 | | | |
| 12.5 Rotate Adapter & Activate Elements | 0 | 0 | 0 | 0 | 0 | | 0 | 400 | 8 | 800 | | | |
| 12.6 Maneuver Tug/SC Adapter | 0 | 0 | 0 | 0 | 0 | | 0 | 400 | 8 | 800 | | | |
| 12.7 Remate Elec. Umbilical Panels | 0 | 0 | 0 | 0 | 0 | | 11 | 400 | 8 | 800 | | | |
| 12.8 Safe Tug/SC for Stowage | 690 | 2 | 0 | 0 | 0 | | 11 | 400 | 8 | 800 | | | |
| 12.9 Rotate Tug into Payload Bay & Secure | | 0 | 0 | 0 | 0 | | 11 | 400 | 8 | 800 | | | |
| 12.10 Configure Tug/SC for Entry Flight | | 0 | 50 | 8 | 40 | | 11 | 400 | 8 | 800 | | | |
| 12.11 [illegible] | | | 0 | 0 | 0 | | 11 | 400 | 8 | 800 | N/A | N/A | N/A |

FOLDOUT FRAME 2

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4.25 Load PCM Data Format | | | | | | | | | | | | | |
| 4.26 Calibrate Measurement System | | | | | | | | | | | | | |
| 4.27 Mate Tug with Kick Stage | | | | | | | | | | | | | |
| 4.28 Verify Interfaces | | | | | | | | | | | | | |
| 4.29 Load & Verify Computer Software | | | | | | | | | | | | | |
| 4.30 System Health Evaluation (SHE) | | | | | | | | | | | | | |
| 4.31 Install Ordnance | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| **5. POST LANDING OPERATION** | | | | | | | | | | | | | |
| 5.1 Safing and Purge | 0 | 9 | 50 | 8 | 40 | | 11 | 25 | 8 | 120 | N/A | N/A | N/A |
| 5.1 Safing and Purge (RLTS) | 0 | 9 | 75 | 8 | 40 | | 11 | 25 | 8 | 120 | | | |
| 5.1 Safing and Purge (AOA/ATO) | 0 | 9 | 75 | 8 | 40 | | 11 | 25 | 8 | 120 | | | |
| 5.2 Remove Tug/Spacecraft | 0 | 0 [13] | 0 [14] | 0 [3] | 0 [15] | | 0 [16] | 0 [17] | 0 [3] | 0 [18] | | | |
| 6., 8., & 10 / 7., 9. (DDT&E/Production Not included in this report) | | N/A | N/A | N/A | N/A | | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| **11. ASCENT FLIGHT** | | | | | | | | | | | | | |
| 11.1 Tug/SC Caution & Warning Monitor & Control | 537 | 0 | 0 | 0 | 0 | | 11 | 25 | 8 | [illegible] | | | |
| 11.2 Tug/SC Predeploy Operation & C/O | 1275 | 0 | 20 | 8 | 400 | | 11 | 400 | 8 | 1800 | | | |
| 11.3 Rotate Tug/SC out of Payload Bay | | 0 | 20 | 8 | 400 | | 11 | 400 | 8 | 800 | | | |
| 11.4 Perform Tug Final Activation & | | 0 | 0 | 0 | 0 | | 11 | 400 | 8 | 800 | | | |
| Status Check | | 0 | 0 | 0 | 0 | | 11 | 400 | 8 | 800 | | | |
| 11.5 Attach RMS to Tug/Spacecraft | 1275 | 0 | 0 | 0 | 0 | | 11 | 400 | 8 | 800 | | | |
| 11.6 Disconnect Umb. & Adapter Latches | 1230 | 0 | 0 | 0 | 0 | | 11 | 400 | 8 | 800 | | | |
| 11.7 Separate Tug Spacraft from Orbiter | | 0 | 0 | 0 | 0 | | 0 | 400 | 8 | 800 | | | |
| 11.8 Activate Tug ACS Thrusters | 1230 [19] | 0 | 10 [20] | 8 [3] | 400 [21] | | 0 [22] | 400 [23] | 8 [3] | 800 [21] | | | |
| **12. TUG RETRIEVAL, ENTRY, LANDING** | | | | | | | | | | | | | |
| 12.1 Transfer Tug/SC Control to Orbiter | 0 | 0 | 0 | 0 | 0 | | 0 | 25 | 8 | 120 | | | |
| 12.2 Command Tug to Preferred Orientation & Attitude | 0 | 0 | 1 | 8 | 40 | | 0 | 25 | 8 | 120 | | | |
| 12.3 Safe Tug for Docking & Perform Terminal Phase Final Maneuver | 0 | 0 | 1 | 8 | 40 | | 0 | 400 | 8 | 800 | | | |
| 12.4 Dock RMS to Tug | 0 | 0 | 1 | 8 | 40 | | 0 | 400 | 8 | 800 | | | |
| 12.5 Rotate Adapter & Activate Elements | 0 | 0 | 0 | 0 | 0 | | 0 | 400 | 8 | 800 | | | |
| 12.6 Maneuver Tug/SC Adapter | 0 | 0 | 0 | 0 | 0 | | 0 | 400 | 8 | 800 | | | |
| 12.7 Remate Elec. Umbilical Panels | 0 | 0 | 0 | 0 | 0 | | 11 | 400 | 8 | 800 | | | |
| 12.8 Safe Tug/SC for Stowage | 690 | 2 | 0 | 0 | 0 | | 11 | 400 | 8 | 800 | | | |
| 12.9 Rotate Tug into Payload Bay & Secure | | 0 | 0 | 0 | 0 | | 11 | 400 | 8 | 800 | | | |
| 12.10 Configure Tug/SC for Entry Flight | | 0 | 50 | 8 | 40 | | 11 | 400 | 8 | 800 | | | |
| 12.11 Verify Tug/Status for Entry Flight | | 0 | 0 | 0 | 0 | | 11 | 400 | 8 | 800 | | | |
| 12.12 Tug/SC C&W Monitor & Control | 690 [25] | 0 [26] | 0 [14] | 0 [3] | 0 [4] | | 11 [10] | 25 [5] | 8 [3] | 120 [24] | N/A | N/A | N/A |
| **13. ABORT** | | | | | | | | | | | | | |
| 13.1 Propellant Dump Safing (RLTS) | 1080 | 9 | 50 | 8 | 40 | | 11 | 25 | 8 | 120 | 10 | 8 | 10 |
| 13.2 Propellant Dump/Safing (AOA/ATO) | <1080 | 9 | 50 | 8 | 40 | | 11 | 25 | 8 | 120 | 10 | 8 | 10 |
| 13.3 Verify Tug Safe for Retrieval | 0 [25] | 0 [13] | 5 [14] | 8 [3] | 40 [4] | | 0 [10] | [illegible] [11] | 8 [3] | 800 [24] | 0 | 0 | 0 |
| **14. MISSION CONTROL** | INCLUDED IN SECTIONS 1-13, 15 | | | | | | INCLUDED IN SECTIONS 1-13, 15 | | | | | | |
| **15. TUG FLIGHT OPERATIONS** | | | | | | | | | | | | | |
| 15.1 Phasing Orbit Injection & Coast | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 15.2 Transfer Orbit Injection & Coast | | | | | | | | | | | | | |
| 15.3 Payload Operational Orbit Injection | | | | | | | | | | | | | |
| 15.4 Deploy Payload | | | | | | | | | | | | | |
| 15.5 Inject into Payload Target Phasing Orbit | | | | | | | | | | | | | |
| 15.6 Inject into P/L Target Rendezvous Orbit | | | | | | | | | | | | | |
| 15.7 Rendezvous with Payload Target | | | | | | | | | | | | | |
| 15.8 Dock with Payload | | | | | | | | | | | | | |
| 15.9 Inject into Return Transfer Orbit, Coast | | | | | | | | | | | | | |
| 15.10 Inject into Return Phasing | | | | | | | | | | | | | |
| 15.11 Inject into Orbiter Rendezvous Orbit | | | | | | | | | | | | | |
| 15.12 Orbiter Rendezvous with Tug | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

FOOTNOTES TO TABLE 3-14

1. The Tug shall issue discrete commands to control payload equipment.

2. A payload serial command link is required for GSE prelaunch and Orbiter predeployment testing.

3. The Tug shall provide a telemetry link from the payload to the Tug/Orbiter interface. A data transfer capability is required for GSE prelaunch and Orbiter predeployment testing.

4. The Tug shall monitor payload environment as follows:

   a. 3/accelerations
   b. 3/temperatures
   c. 3/pressures

5. The Tug shall monitor payload separation and retrieval as follows:

   a. 16 latch positions
   b. 8 parking ring extension/retractions
   c. 1 interface connector

6. Cabling between Tug/payload and Tug/Orbiter for transfer of video signals shall be provided to checkout the planetary payloads prior to launch.

7., 8., 9. Existing payload requirements included in new payload requirements.

10. The Tug shall provide cabling for 30 hardwired caution and warning signals.

11. The Tug shall provide cabling for battery trickle charging during prelaunch.

12. The Tug shall provide cabling between forward and aft interconnects for monitoring of payload battery temperature.

13, 14, 15, 16. Not available.

17. The Tug shall provide signals for separation ordnance ignition. There are 2 squibs per installation and 4 installations per payload.

Table 3-14. Avionics Tug/Spacecraft Interface Requirements

| MISSION PHASE / INTERFACE | TO SPACECRAFT | | | | | FROM SPACECRAFT | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PWR +28V | DIS-CRETE CMDS | DIGITAL COMMAND | | | DIS-CRETE CMDS | FUNC. TO BE MONI-TORED | MONITOR DOWNLINK | | | DIGITAL COMMAND | | | VIDEO | |
| | WATTS | NO. OF CMDS | WORDS | BITS WORD | WORD SEC | NO. OF CMDS | NO. OF FUNCT | WORDS | BITS WORD | WORDS SEC | WORDS | BITS WORD | WORDS SEC | LINKS | FREQ. |
| 1. LAUNCH OPERATIONS | 600* | 10 [11] | TBS | 8 | 250 [2] | 10 | 34 [12/10] | 34 [4/5] | 8 | 250 [3] | 0 | 0 | 0 | 1 [6] | 5MHz [6] |
| 2. TUG/PAYLOAD/ORBITER MATE & CHECKOUT | 600* | 20-60 [1] | TBS | 8 | 250 [2] | 20-50 | 34 [12/10] | 34 [4/5] | 8 | 250 [3] | 0 | 0 | 0 | 2 [6] | 5MHz [6] |
| 3. TUG/SPACECRAFT MATE & CHECKOUT SINGLE / MULTIPLE | 600 / 1000 | 20 / 60 [1] | TBS | 8 | 250 [2] | 20 / 50 | 34 [12/10] | 34 [4/5] | 8 | 250 [3] | 0 | 0 | 0 | 2 [6] | 5MHz [6] |
| 4. REFURBISH & CHECKOUT | N/A | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5. POST LANDING OPERATION | TBD (SMALL) | 0 | 0 | 0 | 0 | 0 | 0 | [4] | | [3] | 0 | 0 | 0 | 0 | 0 |
| 6. 7. 8. 9. 10. DDT&E/PRODUCTION (Not included in this report) | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 11. ASCENT FLIGHT SINGLE / MULTIPLE | 600 / 1000 | 20 / 30 | TBS | 8 | 250 [2] | 20 / 30 | 30 [10] | 34 [4/5] | 8 | 250 [3] | 0 | 0 | 0 | 0 | 0 |
| 12. TUG RETRIEVAL, ENTRY, LANDING | 40 | 20 [1] | TBS | 8 | 250 [2] | 0 | 30 [10] | [4] | 8 | 250 | 0 | 0 | 0 | 0 | 0 |
| 13. ABORT | 600 | 0 [1] | TBS | 8 | 250 [2] | 0 | 30 [10] | 34 [4/5] | 8 | 250 [3] | 0 | 0 | 0 | 0 | 0 |
| 14. MISSION CONTROL | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 0 | 0 |
| 15. TUG FLIGHT OPERATIONS SINGLE | 750 | 20 [1,17] | TBS | 8 | 250 [2] | 20 | 2-6 Δ | 34 [4/5] | 8 | 250 [3] | 0 | 0 | 0 | 0 | 0 |

*Power transfered through Tug

Δ IN VICINITY OF SHUTTLE

ORIGINAL PAGE IS OF POOR QUALITY

## FOOTNOTES TO TABLE 3-15

1. Power changeover is accomplished during the final countdown from ground supplied power. See Table 16.
2. To completely checkout the vehicle during verification and countdown preps, several programs will be loaded into the Tug accounting for 15,000 words of uplink. During the remainder of the launch operations 10% of maximum uplink data is used.
3. An 8-bit data word size (byte) is chosen for both uplink and downlink word sizes because this is the standard interface word size for most state-of-the-art computers.
4. A high rate word uplink rate of 400 words per second is chosen to allow the loading of an 800 word program in 2 seconds. This rate will allow reasonable machine response time for most test sequences.
5. The number of 8-bit words is same as given in Table 22.
6. The word rate of 1800 words is same as given in Table 22.
7. During 2.2 all interface wires are to be "rung-out".
8. This number of words is chosen to sufficiently verify the uplink.
9. The highest operating uplink rate is chosen to verify the uplink (other than computer main memory loading).
10. During 2.2 all interface wires are to be "rung-out".
11. This number of words is chosen to sufficiently checkout the downlink.
12. The highest operating downlink rate is chosen to verify the downlink (other than computer main memory loading).
13. The partial load of Tug pressurants and loading of APS propellant necessitates the possible use of backup safety discrete commands.
14. The Tug spacecraft mate and checkout has a wide range of tasks throughout its subtasks the largest of which is loading the Tug main memory in terms of words and bit rates.
15. The word size is the same as the standard byte oriented machine except for loading the Tug memory in 3.2 where the 32-bit computer word size is assumed.
16. This operation is the same as Footnote 4 except the uplink rate is chosen to allow computer loading in 1 minute via special hardware.
17. Safety monitor functions are used during pressurant load and APS propellant load.
18. The largest block of words for downlink in this section is the computer load echo check where the entire loaded memory is transmitted to ground for a bit-for-bit comparison.
19. The standard 8-bit byte applies for these sections except for computer echo checking for computer loading and TV where 4-bits allow for up to 16 gray code selections.
20. The largest item here is the 48,000 BPS rate imposed by the docking/retrieval simulation where the TV signals must be evaluated through ground hardware.
21. These signals are necessary to control all the pressurants and cryogenic control valves that may be manipulated during tank refurbishment.
22. Same as Footnotes 2 and 14.
23. Same as Footnote 15.
24. These signals are necessary to monitor all the pressurants and cryogenic conditions that may be a safety hazard during Tug refurbishment.
25. These signals are used to establish the condition of all the Tug components during refurbishment.
26. Same as Footnote 6.
27. The deployment adapter valve interface control will be verified during this sequence.
28. Same as Footnote 27.
29. Control safing operations from the ground.
30. Maintain an uplink rate to allow responsive control of venting and dumping valves.
31. The number of 8-bit words is same as given in Table 22.
32. The low rate word rate of 120 words per second is same as given in Table 22.
33. The rate of 400 words per second is required to satisfy the Tug navigation update.

Table 3-15. Avionics Tug/Ground Interface Requirements



| INTERFACE / MISSION PHASE | TO TUG: POWER +28V | TO TUG: SAFETY DISCRETE COMMANDS | TO TUG: DIGITAL COMMAND | | | FROM TUG: DISCRETE COMMAND | FROM TUG: SAFETY FUNCTION TO BE MONITORED | FROM TUG: STATUS MONITOR DOWNLINK | | | FROM TUG: DIGITAL COMMAND | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | WATTS | NO. OF CMDS | WORDS | BITS WORD | WORDS SEC | NO. OF CMDS | NO. OF CMDS | WORDS | BITS WORD | WORDS SEC | WORDS | BITS WORD | WORDS SEC |
| **1. LAUNCH OPERATIONS** | | | | | | | | | | | | | |
| 1.1 Launch Readiness Verification & Countdown Prep. | 1324 | 0 | 15000 | 8 | 400 | N/A | 0 | 400 | 8 | 800 | N/A | N/A | N/A |
| 1.2 Load Propellants & Pressurants | | | 1500 | | 40 | | 0 | 450 | 8 | 1800 | | | |
| 1.3 Backout/Payload Changeout | | | 1500 | | 40 | | 0 | 450 | 8 | 1800 | | | |
| 1.3A Pad Abort | | | 1500 | | 40 | | 0 | 450 | 8 | 1800 | | | |
| 1.4 Close Cargo Bay Doors, etc. | | | 1500 | | 40 | | 0 | 450 | 8 | 1800 | | | |
| 1.5 Final Countdown | 1324 [1] | 0 | 1500 [2] | 8 [3] | 40 [4] | | 0 | 450 [5] | 8 [3] | 1800 [6] | | | |
| **2. TUG/PAYLOAD/ORBITER MATE & C/O** | | | | | | | | | | | | | |
| 2.1 Install Tug/P/L in Orbiter at OPF | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | | | |
| 2.2 Interface Verification | | 9 | 100 | 8 | 400 | | 11 | 25 | 8 | 1800 | | | |
| 2.3 Tug Monitoring | | 0 [7] | 0 [8] | 0 [3] | 0 [9] | | 11 | 25 [11] | 8 [3] | 120 [12] | N/A | N/A | N/A |
| **3. TUG/SPACECRAFT MATE & C/O** | | | | | | | | | | | | | |
| 3.1 Tug & Spacecraft Mate | | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3.2 Load Tug Computer Flt. Software | | 0 | 64000 | 32 | 1000 | | 0 | 64000 | 32 | 1000 | 0 | 0 | 0 |
| 3.3 Docking/Retrieval Simulation | | 0 | 0 | 0 | 0 | | 0 | N/A(TV) | 4 | 12000 | 0 | 0 | 0 |
| 3.4 Functional Interface Test (FIT) | | 0 | 400 | 8 | 400* | | 0 | 400 | 8 | 1800 | 0 | 0 | 0 |
| 3.5 Communication Verification | | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3.6 Communication Verification | | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3.7 Install Flight Battery | | 0 | 1 | 8 | 40 | | 0 | 2 | 8 | 120 | 0 | 0 | 0 |
| 3.8 Connect Ordnance | | 0 | 0 | 0 | 0 | | 0 | 0 | 8 | 120 | 0 | 0 | 0 |
| 3.9 Move to APS Prep. Loading Bay | | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3.10 Partial Tug Pressurant Load | | 9 | 50 | 8 | 40 | | 3 | 60 | 8 | 800 | 0 | 0 | 0 |
| 3.11 Load APS Propellant | | 4 | 60 | 8 | 40 | | 5 | 70 | 8 | 800 | 0 | 0 | 0 |
| 3.12 Install Payload in Cannister | | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3.13 Deliver Payload to Pad | | 0 [13] | 0 [14] | 0 [15] | 0 [16] | | 0 [17] | 0 [18] | 0 [19] | 0 [20] | 0 | 0 | 0 |
| **4. REFURBISH & CHECKOUT** | | | | | | | | | | | | | |
| 4.1 Safe & Remove Unexpended Ordnance | | 0 | 0 | 0 | 0 | | 0 | 8 | 8 | 120 | 0 | 0 | 0 |
| 4.2 Drain & Purge APS | | 4 | 60 | 8 | 400 | | 5 | 20 | 8 | 800 | 0 | 0 | 0 |
| 4.3 Remove Flight Battery | | 0 | 1 | 8 | 40 | | 0 | 2 | 8 | 120 | 0 | 0 | 0 |
| 4.4 Leak Check Pressurant System | | 4 | 50 | 8 | 40 | | 3 | 60 | 8 | 800 | 0 | 0 | 0 |
| 4.5 Leak Check $LO_2$ Tank | | 9 | 10 | 8 | 40 | | 0 | 100 | 8 | 1800 | 0 | 0 | 0 |
| 4.6 Leak Check $LH_2$ Tank | | 9 | 10 | 8 | 40 | | 0 | 100 | 8 | 1800 | 0 | 0 | 0 |
| 4.7 Service Fuel Cells & Leak Check Reactant System | | 9 | 10 | 8 | 40 | | 0 | 100 | 8 | 1800 | 0 | 0 | 0 |
| 4.8 Vent Remaining Pressurant | | 4 | 50 | 8 | 40 | | 3 | 60 | 8 | 800 | 0 | 0 | 0 |
| 4.9 Separate Tug From Adapter | | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.10 Tug Visual Damage Inspection | | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.11 Clean Tug & Prepare to Move | | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.12 Move into TPF Checkout Area | | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.13 Isolate Failed Hardware Causing | | 9 | 15000 | 8 | 400 | | 0 | 400 | 8 | 1800 | 0 | 0 | 0 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4.9 Separate Tug From Adapter | | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.10 Tug Visual Damage Inspection | | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.11 Clean Tug & Prepare to Move | | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.12 Move into TPF Checkout Area | | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.13 Isolate Failed Hardware Causing Mission Anomalies | | 9 | 15000 | 8 | 400 | | 0 | 400 | 8 | 1800 | 0 | 0 | 0 |
| 4.14 Scheduled Tug Pre-Main. Tests | | 9 | 15000 | 8 | 400 | | 0 | 400 | 8 | 1800 | 0 | 0 | 0 |
| 4.15 Sch. Tug Main. & Modification | | 9 | 15000 | 8 | 40 | | 0 | 400 | 8 | 1800 | 0 | 0 | 0 |
| 4.16 Adapter Visual Damage Inspection | | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.17 Clean & Prepare to Move Adapter | | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.18 Move Adapter into TPF C/O Area | | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.19 Isolate Adpt Hardware Causing Anomalies | | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.20 Scheduled Adapter Main. Tests | | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.21 Mate Tug with Adapter & Verify Interfaces | | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.22 Electrical Pre-Power Checks | | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.23 Mechanical Alignment Verification | | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.24 Apply Power To Tug | | 0 | 40 | 8 | 40 | | 0 | 25 | 8 | 120 | 0 | 0 | 0 |
| 4.25 Load PCM Data Format | | 0 | 4000 | 8 | 200 | | 0 | 400 | 8 | 200 | 0 | 0 | 0 |
| 4.26 Calibrate Measurement System | | 0 | 400 | 8 | 400 | | 0 | 400 | 8 | 1800 | 0 | 0 | 0 |
| 4.27 Mate Tug with Kick Stage | | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.28 Verify Interfaces | | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.29 Load & Verify Computer Software | | 0 | 64000 | 32 | 1000 | | 0 | 64000 | 32 | 1000 | 0 | 0 | 0 |
| 4.30 System Health Evaluation (SHE) | | 9 | 30000 | 8 | 1000 | | 11 | 1000 | 8 | 800 | 10 | 8 | 10 |
| 4.31 Install Ordnance | | 0 [21] | 0 [22] | 0 [23] | 0 | | 0 [24] | 0 [25] | 0 [3] | 0 [26] | 0 [27] | 0 [3] | 0 [2] |
| **5. POST LANDING OPERATION** | | | | | | | | | | | | | |
| 5.1 Safing and Purge | | 0 | 50 | 8 | 40 | | 0 | 25 | 8 | 120 | 0 | 0 | 0 |
| 5.1 Safing and Purge (RLTS) | | 0 | 75 | 8 | 40 | | 0 | 25 | 8 | 120 | 0 | 0 | 0 |
| 5.1 Safing and Purge (AOA/ATO) | | 0 | 75 | 8 | 40 | | 0 | 25 | 8 | 120 | 0 | 0 | 0 |
| 5.2 Remove Tug/Spacecraft | | 0 [29] | 0 [3] | 0 | 0 [30] | | 0 | N/A [31] | 0 [3] | 0 [32] | 0 | 0 | 0 |
| 6., 8. & 10 (DDT&E/Production 7., 9. Not included in this report) | | N/A | N/A | N/A | N/A | | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| **11. ASCENT FLIGHT** | | | | | | | | | | | | | |
| 11.1 Tug/SC Caution & Warning Monitor & Control | 0 | 0 | [illegible] | 0 | 0 | | N/A | 25 | 8 | 120 | N/A | N/A | N/A |
| 11.2 Tug/SC Predeploy Operation & C/O | | | 400 | 8 | 400 | | | 400 | 8 | 1800 | | | |
| 11.3 Rotate Tug/SC out of Payload Bay | | | 0 | 0 | 0 | | | 400 | 8 | 800 | | | |
| 11.4 Perform Tug Final Activation & Status Check | | | 0 | 0 | 0 | | | 400 | 8 | 800 | | | |
| 11.5 Attach RMS to Tug/Spacecraft | | | 0 | 0 | 0 | | | 400 | 8 | 800 | | | |
| 11.6 Disconnect Umb. & Adapter Latches | | | 0 | 0 | 0 | | | 400 | 8 | [illegible] | | | |
| 11.7 Separate Tug Spacraft from Orbiter | | | 0 | 0 | 0 | | | 400 | 8 | 800 | | | |
| 11.8 Activate Tug ACS Thrusters | | | [10] | 8 | 400 [33] | | | 400 [5] | 8 [3] | 800 | | | |
| **12. TUG RETRIEVAL, ENTRY, LANDING** | | | | | | | | | | | | | |
| 12.1 Transfer Tug/SC Control to Orbiter | | | 0 | 0 | 0 | | | 25 | 8 | 120 | | | |
| 12.2 Command Tug to Preferred Orientation & Attitude | | | 1 | 8 | 40 | | | 25 | | 120 | | | |
| 12.3 Safe Tug for Docking & Perform Terminal Phase Final Maneuver | | | 0 | 0 | 0 | | | 400 | | 800 | | | |
| 12.4 Dock RMS to Tug | | | | | | | | 400 | | | | | |
| 12.5 Rotate Adapter & Activate Elements | | | | | | | | 400 | | | | | |
| 12.6 Maneuver Tug/SC Adapter | | | | | | | | 400 | | | | | |
| 12.7 Remate Elec. Umbilical Panels | | | | | | | | 400 | | | | | |
| 12.8 Safe Tug/SC for Stowage | | | | | | | | 400 | | | | | |
| 12.9 Rotate Tug into Payload Bay & Secure | | | | | | | | 400 | | | | | |
| 12.10 Configure Tug/SC for Entry Flight | | | | | | | | 400 | | | | | |
| 12.11 Verify Tug/Status for Entry Flight | | | | | | | | 400 | | 800 | | | |
| 12.12 Tug/SC C&W Monitor & Control | | | | | | | | 25 [5] | 8 [3] | 120 [31] | N/A | N/A | N/A |
| **13. ABORT** | | | | | | | | | | | | | |
| 13.1 Propellant Dump Safing (RLTS) | | | | | | | | 25 | 8 | 120 | 0 | 0 | 0 |
| 13.2 Propellant Dump/Safing (AOA/ATO) | | | 0 | 0 | 0 | | | 25 | 8 | 120 | 0 | 0 | 0 |
| 13.3 Verify Tug Safe for Retrieval | | | 5 | 8 | 40 | | | 150 [11] | 8 [3] | 800 [31] | 10 | 8 [3] | 10 |
| **14. MISSION CONTROL** | | | INCLUDED IN SECTIONS 1-13,15 | | | | | INCLUDED IN SECTIONS 1-13, 15 | | | | | |
| **15. TUG FLIGHT OPERATIONS** | | | | | | | | | | | | | |
| 15.1 Phasing Orbit Injection & Coast | | | 40 | 8 | 250 | | | 450 | 8 | 1800 | 0 | 0 | 0 |
| 15.2 Transfer Orbit Injection & Coast | | | 40 | 8 | 250 | | | 450 | 8 | 1800 | 0 | 0 | 0 |
| 15.3 Payload Operational Orbit Injection | | | 40 | 8 | 250 | | | 450 | 8 | 1800 | 0 | 0 | 0 |
| 15.4 Deploy Payload | | | 4 | 8 | 40 | | | 450 | 8 | 6000 | 0 | 0 | 0 |
| 15.5 Inject into Payload Target Phasing Orbit | | | 40 | 8 | 250 | | | 450 | 8 | 1800 | 0 | 0 | 0 |
| 15.6 Inject into P/L Target Rendezvous Orbit | | | 40 | 8 | 250 | | | 450 | 8 | 1800 | 0 | 0 | 0 |
| 15.7 Rendezvous with Payload Target | | | 4 | 8 | 40 | | | 450 | 8 | 6000 | 0 | 0 | 0 |
| 15.8 Dock with Payload | | | 4 | 8 | 40 | | | 450 | 8 | 1800 | 0 | 0 | 0 |
| 15.9 Inject into Return Transfer Orbit, Coast | | | 40 | 8 | 250 | | | 450 | 8 | 1800 | 0 | 0 | 0 |
| 15.10 Inject into Return Phasing | | | 40 | 8 | 250 | | | 450 | 8 | 1800 | 0 | 0 | 0 |
| 15.11 Inject into Orbiter Rendezvous Orbit | | | 40 | 8 | 250 | | | 450 | 8 | 1800 | 0 | 0 | 0 |
| 15.12 Orbiter Rendezvous with Tug | 0 | 0 | 0 [4] | 0 [3] | 0 [33] | N/A | N/A | 450 [5] | 8 [3] | 1800 [6] | 0 | 0 | 0 |

FOLDOUT FRAME 2

# APPENDIX A

## AVIONICS SUPPORT TASKS WITHIN OPERATIONAL PHASES

## Table 1. Avionics Tasks During Launch Operations

| MISSION PHASE | AVIONICS TASKS |
|---|---|
| 1.1 Launch Readiness Verification & Countdown Preparations | Provide instrumentation and data management capabilities to collect and display all needed data for all avionic, structural, mechanical, propulsion, and thermal subsystems. Collect and display data to payload/mission specialist stations and to appropriate ground monitor and control stations. Provide required software to interface with LPS. |
| 1.2 Load all Propellant & Pressurants into Tug | Provide instrumentation, data management and interface panels to monitor and control operations including all safety functions. Provide interface with LPS for prelaunch & countdown data display at appropriate ground control stations. Provide LPS interface software as required. |
| 1.3 Backout/Payload Changeout<br>Note: Payload changeout tasks and functional interface requirements are based on payload changeout occurring prior to attaining final two hour standby status and therefore, prior to propellant loading. The changeout room is in place with an environmental seal established between the room and Orbiter skin, and the payload bay doors are closed. | Provide instrumentation & data management capability to place Tug systems in safe condition, verify accomplishment, and display data on Orbiter mission/payload specialist panel and appropriate ground control panels. Includes providing all interface lines and panels to transmit data from Tug to Orbiter and ground locations. Provide required software input to LPS. Monitor safety critical functions. |
| 1.3A Pad Abort | Provide instrumentation and data management capability to successfully abort mission without violating safety requirements. Provide instrumentation and data management capability to monitor and control Tug propellant loading/termination operations and display required data at payload/mission specialist station and ground control stations. Includes interface panels at Orbiter mold line and aft bulkhead and all interconnecting lines. |
| 1.4 Close Cargo Bay Doors<br>Note: These are basically Orbiter tasks During these tasks the functional interfaces identified must be maintained, but are not associated with a discrete subtask. | Provide instrumentation, data management, interface panels (Orbiter aft bulkhead and mold line) and lines to monitor Tug status during this and other Orbiter pre-launch and standby activity. Provide interface with LPS for data display at appropriate ground control stations as well as caution and warning display at payload/mission specialist panel. Provide required interface software. |
| 1.5 Final Countdown | Provide instrumentation, data management, interface panels (Orbiter aft bulkhead and mold lines), and lines to monitor Tug status. Provide interface with LPS for prelaunch & countdown data display at the appropriate ground control station as well as caution and warning display at payload/mission specialist station. Provide required interface software. |

## Table 2. Avionics Tasks During Tug/Spacecraft/Orbiter Mate

| MISSION PHASE | AVIONICS TASKS |
|---|---|
| 2.1 Install Tug & Payload in Orbiter | All systems either turned off or in power down mode. Instrumentation and DMS system will monitor safety functions. Provide instrumentation and data management capability to verify Tug/payload interfaces. Monitor safety functions. |
| 2.2 Verify all Tug/Shuttle Interfaces | Provide instrumentation and data management capability to verify appropriate structural, fluid and avionic interfaces. Monitor safety functions. |
| 2.3 Tug Monitoring | Provide instrumentation and data management capability to collect and display critical safety and warning parameters at a location external to the Orbiter payload bay. This location should be one of the MLP rooms with available access during all Shuttle buildup and transport operations. During Orbiter tow from OPF to VAB data could be displayed at payload/mission specialist station. Instrumentation for data gathering should be normal flight instrumentation. All non-flight items must be located such that payload bay access is not required. |

## Table 3. Avionics Tasks During Tug/Spacecraft Mate & Checkout

| MISSION PHASE | AVIONICS TASKS |
|---|---|
| 3.1 Mechanically Mate the Spacecraft to the Tug | Provide avionic interfaces between Tug and Spacecraft and verify. |
| 3.2 Load and Verify Computer Flight Software | Load Tug computer flight program via LPS and verify proper response. |
| 3.3 Verify Docking/Retrieval Capability | Verify docking/retrieval mechanism functions. |
| 3.4 Functionally Verify all Tug/Kick Stage/Spacecraft Interfaces | Verify single point ground and bus isolation. To the maximum extent possible, exercise all Tug/Kick Stage/Spacecraft systems through the mission profile (liftoff thru S/C separation) using the MSS/PSS flight hardware. Data will be monitored and compared to establish criteria for go, no-go conditions. All ordnance functions and separation latches will be monitored for proper event occurrence. |
| 3.5 Spacecraft to STDN/TDRSS/SCF Communication Verification (Open Loop) | Verify the payload uplink and downlink to each segment's controller ground station. |
| 3.6 Payload to Orbiter Communications Verification (Open Loop) | Verify RF compatibility between the Orbiter and Tug communications systems. After RF lock-on between Tug and Orbiter perform all mission communication routines. All normal commands and proper responses will be verified. |
| 3.7 Install Flight Battery | Install battery and connect to distribution system. Verify interfaces. |
| 3.8 Connect Ordnance and Verify Safe | Verify no current at each ordnance connector with power on/off, connect ordnance interface connectors. Verify ordnance items in safe configuration. |
| 3.9 Move to APS Propellant Loading Bay | None. |
| 3.10 Partial Tug Pressurant Load | Monitor Operation. |
| 3.11 Load APS, Leak Check & Secure | Monitor Operation. |
| 3.12 Install Payload in Canister | Change umbilicals. |
| 3.13 Deliver Payload (Tug and Spacecraft) to Pad | Monitor Operations. |

## Table 4. Avionics Tasks During Refurbish and Checkout

| MISSION PHASE | AVIONICS TASKS |
|---|---|
| 4.1 Safe and Remove Unexpended Ordnance | Use flight instrumentation if available. |
| 4.2 Drain and Purge APS | Use flight instrumentation. |
| 4.3 Remove Flight Batteries for Refurbishment | Provide battery access to disconnect flight battery from Tug power system. |
| 4.4 Verify Integrity of Pressurization System | Use flight instrumentation. |
| 4.5 Verify $LO_2$ System Integrity | Use flight instrumentation. |
| 4.6 Verify $LH_2$ System Integrity | Use flight instrumentation. |
| 4.7 Service Fuel Cells for Deactivation, Drain $H_2O$ and Leak Check System | Connect fuel cell servicing GSE, drain $H_2O$ from system, purge fuel cells to remove moisture and lock up with a blanket pressure of 19 ±1 psia. Stabilize pressure for 30 minutes. Leak check (decay) system for 30 min. Vent system to 19 ±1 psia and lock up. |
| 4.8 Vent Remaining Pressurant | Use flight instrumentation. |
| 4.9 Separate Tug from Adapter | Provide umbilical disconnects. Use flight instrumentation. |
| 4.10 Post Flight Visual Inspection of Designated areas for flight and/or Handling Damage | Provide access doors to visually inspect components, subsystems, |
| 4.11 Clean Tug & Prepare to Move | Provide access to clean avionics system components, umbilical, harness. |
| 4.12 Move Tug to Clean Area for Maintenance & Checkout | None. |
| 4.13 Isolate Failed Hardware Causing Mission Anomalies | Using flight performance data as an information source, stimulate suspected systems/components with GSE and isolate analomous performance to replaceable LRUs. Tag discrepant units for replacement. |
| 4.14 Scheduled Tug Pre-Maintenance Tests | Install checkout GSE, perform measurement systems end to end calibration. |
| 4.15 Scheduled Tug Maintenance & Modification | Perform non destructive testing on components, subsystems and harness as required by operating time/life cycle requirements and/or manufacturers specifications. |
| 4.16 Adapter Visual Damage Inspection | Provide access doors to inspect component, subsystems and harness. |
| 4.17 Clean and Prepare to Move Adapter | Provide access to clean components, subsystems and harness. |
| 4.18 Move Adapter into FPF Checkout Area | None. |
| 4.19 Isolate Adapter Hardware Causing Anomalies | Using flight data as an information source, stimulate suspected adapter systems and troubleshoot as required to accomplish isolation of components (LRU) which have caused anomalies on the previous mission. |
| 4.20 Scheduled Adapter Maintenance Tests | Install checkout GSE, and perform measurement systems end to end calibration. Perform non-destructive testing on components, subsystems and harness as required by operating time/life cycle requirements and/or manufacturers specification. |
| 4.21 Mate Tug With Adapter and Verify Interfaces | Position adapter for mating with Tug, move Tug work stand platforms to accommodate adapter, mate and verify electrical system interfaces. Also verify continuity. Verify all mechanical interfaces. |

## Table 4. Avionics Tasks During Refurbish and Checkout, Contd

| MISSION PHASE | AVIONICS TASKS |
|---|---|
| 4.22 Electrical Pre-Power Checks | Verify single point ground, connect GSE and verify bus isolation. |
| 4.23 Mechanical Alignment Verification | Verify mechanical alignment of engine to Tug, deployment adapter to Tug, S/C adapter to Tug and guidance component platform to Tug. |
| 4.24 Apply Power To Tug | Energize Tug subsystems for downstream testing and verify power quality. Apply ground power to Tug & utilize the LPS to switch on/off each subsystem. LPS to monitor power bus for noise and ripple and compare with a pre-established criteria. Verify Tug/Spacecraft interface distribution. |
| 4.25 Load PCM Data Format | Mission peculiar data format to be loaded into LPS and transfer to on-board computer. Verify compatibility between Tug computer and ground control. |
| 4.26 Calibrate Measurement System | Utilize the LPS/Tug computers to stimulate end instruments for a calibration at a minimum of three voltage levels. |
| 4.27 Mate Tug with Kick Stage | Provide avionics interfaces and umbilical connections. |
| 4.28 Verify Interfaces | Verify signal continuity across Tug/Kick Stage Interface and Kick Stage power activation. Verify correct pin-to-pin continuity and power distribution. Utilize the LPS to command signals across Tug/Kick Stage Interface and verify response. |
| 4.29 Load & Verify Computer Software | Utilize the LPS to load the Tug computer with mission peculiar test software. |
| 4.30 System Health Evaluation | Verify Tug subsystem performance is in accordance with established go/no-go criteria.With the Tug or Tug/Kick Stage in a simulated flight posture, ordnance function monitored via special cabling, command the Tug/Kick Stage through the normal mode of operation. All commandable backup redundancy modes will be exercised. All time critical sequences will be verified. Selected data points will be monitored to compare with pre-established trend data. |
| 4.31 Install Ordnance | Verify Interfaces. |

## Table 5. Avionics Tasks During Post Landing Operations

| MISSION PHASE | AVIONICS TASKS |
|---|---|
| 5.1 Safing and Purge | Provide instrumentation and data management capability to monitor/control all subsystems until all safety requirements have been verified. Display power, vent, pressure and purge data at payload/mission specialists station. Monitor safety functions. |
| 5.1a Safing & Purge (Abort & RLTS) | Provide instrumentation and data management capability to monitor/control all subsystems until all safety requirements have been verified. Display vent, pressure, power and purge gas data at payload/mission specialists station. Monitor safety functions. |
| 5.1b Safing & Purge (Abort AOA/ATO) | Provide instrumentation and data management capability to monitor/control all subsystems until all safety requirements have been verified. Display, power, pressure, vent and purge data at payload/mission specialists station. Monitor safety functions. |
| 5.2 Remove Tug/Spacecraft from Orbiter. | Monitor safety critical functions on Tug and Spacecraft. Provide instrumentation capability to monitor tank and insulation condition at payload/mission specialists station during this task. Provide avionics interface disconnect panel/receptacles for all Tug/Shuttle avionics interface connections. |

## Table 6. Avionics Tasks During DDT&E and Production

| MISSION PHASE | | AVIONICS TASKS |
|---|---|---|
| 6 thru 10 | Avionics Requirements During DDT&E & Production | No requirements have yet been developed for these phases. |

## Table 7. Avionics Tasks During Ascent Flight

| MISSION PHASES | | AVIONICS TASKS |
|---|---|---|
| 11.1 | Perform Tug/Spacecraft Caution & Warning, Monitor & Control Functions | Provide instrumentation, data management & communication capabilities to display required information at MSS/PSS station, to flight crew and to ground stations.<br>• Provide control & monitoring capability to automatically perform following functions at Orbiter ignition:<br>Close $LH_2$ and $LO_2$ tank vent valves<br>Terminate helium purge<br>Open purge bag vent valves<br>• Manual override capability provided from Orbiter crew compartment C&W panel.<br>• Provide C&W monitor and control panel in crew compartment and at MSS/PSS stations. This panel will be interconnected with other displays and controls, aural alarm & illuminated talkback. In addition, provide C&W data to be transmitted through Orbiter communication system to ground stations & ground controllers.<br>• Provide electrical power.<br>• Provide capability to record C&W data and Tug flight performance data.<br>• Provide control & monitoring capability to automatically open $LH_2$ & $LO_2$ tank vent valves at ~ 200 sec or > 300,000 ft altitude.<br>• Provide controls to activate zero-g vent systems and close positive g vent valves. |
| 11.2 | Perform Tug/Spacecraft Operation & Checkout Prior to Deployment of Tug/Spacecraft from Orbiter | • Provide instrumentation, data management and communication capabilities to display required information and MSS/PSS, to flight crew and to ground stations.<br>• Provide through Orbiter communication system authority to receive command data & transmit status data from/to ground stations.<br>• In Tug DMS, provide program to perform predeployment activation and checkout.<br>• Provide communication link to Orbiter to receive ground command to initiate programmed Tug predeployment activation & checkout.<br>• Provide hardwire link from Orbiter through Tug to Spacecraft to initiate activation and checkout of Spacecraft subsystems.<br>• Provide hardwire link to transmit status data from Spacecraft through Tug to Orbiter.<br>• Provide indication for Tug/Spacecraft systems in go status for deployment. (No-go status results in abort condition, see Block 12.2). |
| 11.3 | Rotate Tug & Spacecraft Out of Orbiter Payload Bay | • Provide, monitor and control all operational commands, including status to MSS/PSS Stations.<br>• Monitor safety critical items.<br>• Provide controls to initiate and operate drive mechanism.<br>• Provide instrumentation and DMS display capability to verify status.<br>• Provide communication link to transmit status information to Orbiter communication for relay of data to ground controllers.<br>• Maintain programmed orientation & attitude during deployment operations.<br>• Provide electrical power |

Table 7. Avionics Tasks During Ascent Flight, Contd

| MISSION PHASES | AVIONICS TASKS |
|---|---|
| 11.4 Perform Final Tug Activation and Status Checks | • Provide, monitor & control all operational commands to verify status of all Tug/Spacecraft subsystems and display data at MSS/PSS stations. Monitor safety critical functions.<br>• Provide controls and DMS to open non-thrust vents for $H_2$ and $O_2$.<br>• Provide controls to disable zero-g vent devices.<br>• Provide controls to activate fuel cell & changeover power from Orbiter to internal.<br>• Provide data link to update G&N state vector.<br>• Provide RF link for Tug to communicate with Orbiter after umbilical panel disconnect.<br>• Provide instrumentation, DMS, data link to verify Tug readiness and commit to deploy. Tug computer program to perform verification on command from ground controller or Orbiter crew.<br>• Provide voice and data uplink for ground controller to verify Tug/Spacecraft commit to deploy. |
| 11.5 Attach RMS to Tug/Spacecraft | Provide capability to monitor attachment of RMS and subsequent deployment operations. Monitor all safety critical functions. |
| 11.6 Disconnect Umbilicals & Adapter Latches in Anticipation of Tug/Spacecraft Separation from Orbiter | Provide, monitor and control all operational commands. Monitor all safety functions. Provide controls to initiate retracting umbilical panels and demating of Tug from adapter. Provide instrumentation and DMS link to monitor demating and release operations from MSS display and also at ground controller station. |
| 11.7 Separate Tug/Spacecraft from Orbiter | • Provide, monitor and control all operational commands. Monitor all safety functions.<br>• Provide capability to visually monitor from MSS panel as in 11.5.<br>• Provide instrumentation, DMS and communication to transmit Tug status data to Orbiter for monitor and control.<br>• Provide control, data link to enable ACS<br>• Provide instrumentation, DMS and data link to monitor and control Tug operation and performance at ground station through Orbiter |
| 11.8 Activate Tug ACS Thrusters | Provide controls, communication subsystem, and data links to receive command and send signal to ACS subsystem to energize ACS thruster propellant control valves. |

## Table 8. Avionics Tasks During Orbiter Retrieval of Tug, Entry, Landing

| MISSION PHASE | AVIONICS TASKS |
|---|---|
| 12.1 Transfer Tug/Spacecraft Control from Ground Controller to Orbiter Crew | Retrieval by Orbiter is based on the following guidelines:<br>• Spacecraft is inert and safed with all appendages retracted into stowed position.<br>• Tug MPS has been safed. All propellants other than FPR, have been expended prior to rendezvous maneuvers by Orbiter.<br>• Tug active subsystems are communication, DMS, G&N and ACS.<br>Provide communication system compatible with AFSCF and STDN networks.<br>Provide RF compatibility with Orbiter and ground stations. |
| 12.2 Command Tug to Preferred Orientation & Attitude | Provide transponder compatible with Orbiter radar for rendezvous.<br>Provide communication, DMS and flight control to receive commands and compute signals for ACS.<br>Provide instrumentation, DMS and data link to transmit status data to Orbiter. |
| 12.3 Safe Tug for Docking & Perform TPF Maneuver | Provide instrumentation, DMS and communication subsystems to verify status and safety of Tug/Spacecraft. Transmit measurements, excitation and commands to other subsystems. Transmit status and safety data to Orbiter.<br>Provide G&N, DMS & flight control to maintain commanded orientation and attitude.<br>Perform controls to deactivate transponder at direction of Orbiter.<br>Provide ACS, communication link to receive Orbiter commands & execute. Transmit status to preferred docking attitude. |
| 12.4 Dock RMS to Tug | Provide controls to transmit commands to ACS to stabilize Tug/Spacecraft for mating with RMS.<br>Shutdown ACPS.<br>Provide RF communication link and controls to deactivate guidance and navigation and flight control subsystems.<br>Provide RF communication link and control to safe ACPS. |
| 12.5 Rotate Adapter & Activate Elements to Accept Tug | Provide controls and instrumentation to perform adapter readiness functions:<br>Umbilical panels in retracted position.<br>Tug-adapter latches in retracted position.<br>Power available to drive mechanism.<br>Provide controls and instrumentation to rotate deployment adapter to position for accepting Tug/Spacecraft.<br>Relay status to ground station. |
| 12.6 Maneuver Tug/Spacecraft into Adapter | Provide instrumentation and communication for Orbiter crew to monitor and control Tug safety status.<br>Relay status to ground station. |
| 12.7 Remate Electrical Umbilical Panels | Provide control capability to activate Tug-to-adapter latches.<br>Monitor status of latch operations.<br>Provide controls & instrumentation to activate & monitor umbilical remate.<br>Provide necessary power.<br>Relay status to ground control. |

Table 8. Avionics Tasks During Orbiter Retrieval of Tug, Entry, Landing, Contd

| MISSION PHASE | AVIONICS TASKS |
|---|---|
| 12.8 Safe Tug/Spacecraft for Stowage | Provide transfer switch from Tug power to Orbiter power. |
| | Provide for deactivation of fuel cell power system. |
| | Provide controls to safe all Tug subsystems. |
| | Monitor Tug status and relay to ground station. |
| 12.9 Retract Tug into Payload Bay and Secure | Provide controls and power to activate and operate adapter rotation drive. |
| | Provide instrumentation and DMS display capability to verify status of drive mechanism. |
| | Provide communication link to transmit status to ground station. |
| 12.10 Configure Tug/Spacecraft for Entry Flight & Remate Fluid Umbilicals | Provide controls and sensing system for maintaining pressure in main propellant tanks and purge bags. |
| | Display status at MSS/PSS. |
| | Relay status to ground stations. |
| | Provide program to purge MPS liquid hydrogen tank and lines. |
| | Provide instrumentation to monitor Tug subsystem status. |
| 12.11 Verify Tug/Spacecraft Status | Provide instrumentation and hardwire C&W monitor and control for Orbiter crew safety. |
| | Transmit status data to ground control and receive confirmation of Tug/Spacecraft safe condition. |
| 12.12 Tug/Spacecraft C&W Monitor and Control | Provide instrumentation & hardwire C&W monitor & control for Orbiter crew safety. |
| | Transmit status data to ground control and receive confirmation of Tug/Spacecraft safe condition. |

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## Table 9. Avionics Tasks During Abort Operations

| MISSION PHASE | AVIONICS TASKS |
|---|---|
| 13.1 Propellant Dump/Safing Operations (Return to Launch Site) | Configure subsystems and software to permit safe dumping of Tug/Spacecraft propellants & safing of Tug/Spacecraft. |
| | Provide automatic sequences for propellant dump after initiation of dump procedure by Orbiter crew. |
| | Provide program stored in Tug DMS to perform dump operation automatically. |
| | Provide backup program in Orbiter. |
| | Provide instrumentation & lines to initiate & monitor dump progress. |
| | Relay abort status data to ground station. |
| | Provide electrical power. |
| | Provide program to safely shutdown dump operation after receiving depletion signal. |
| | Provide backup program in Orbiter to safely terminate dump operations. |
| | Provide instrumentation & data link to transmit status data to Orbiter. |
| | Provide instrumentation, DMS and data lines to inert propellant system and abort pressurization system. |
| 13.2 Propellant Dump Safing Operations (Abort to Orbit/Abort once around) | Configure subsystems and activate software to perform propellant dump operation and safing of Tug/Spacecraft. |
| | Provide data link to Orbiter, DMS, and data lines to subsystems to receive ground control command to terminate activation and C/O procedure. |
| | Provide DMS & data links to subsystems to passivate all subsystems except DMS. |
| | Provide instrumentation and data link to transmit status data to Orbiter. |
| 13.2 Propellant Dump Safing Operations (Continued) | Provide DMS and lines to initiate pressurization of propellant tanks. |
| | Provide instrumentation, DMS and lines to control dump process and transmit Tug status data to Orbiter and relay to ground station. |
| | Provide program to safely shutdown dump operation of $LO_2$ and $LH_2$ tanks after receipt of sensor signals. |
| | Provide program to configure Tug propulsion system for return-to-ground mode. |
| 13.3 Abort Operations After Tug and Spacecraft Have Been Deployed From Orbiter (also Verify Tug Safe for Retrieval) | Provide communication, DMS, G&N, ACS to: |
| | Establish RF communication link with Orbiter. |
| | Stabilize and orient Tug/Spacecraft. |
| | Perform commands received from Orbiter. |
| | Transmit status data to Orbiter including: main propulsion system controls, lines and sensors to safe propellant tanks and pressurization system, and attitude control system to perform maneuvers and stabilize Tug/Spacecraft. |

## Table 10. Avionics Tasks for Mission Control

| MISSION PHASE | AVIONICS TASKS |
|---|---|
| 14. Avionics Requirements for Mission Control | The avionics requirements for mission control are included in each of the Operational Phases of the mission (Sections 1, 2, 3, 4, 5, 11, 12, 13, 15). |

## Table 11. Avionics Tasks During Tug Flight

| MISSION PHASE | AVIONICS TASKS |
|---|---|
| 15.1 Phasing Orbit Injection Maneuvers & Coast (when Tug is clear of Orbiter) | Provide all operational commands and monitor/control those Tug/payload parameters that are critical for mission success:<br>Perform POI burn (main engine).<br>Orbiter monitor departure & perform on-orbit operations.<br>Position and velocity update.<br>Report status to Tug operations center.<br>Coast |
| 15.2 Transfer Orbit Injection Maneuvers and Coast | Provide all operational commands and monitor/control those Tug/payload parameters that are critical for mission success:<br>Attitude update.<br>Position and velocity update.<br>Compute TOI burn parameters.<br>Maneuver to required attitude for TOI burn.<br>Verify subsystems ready for burn.<br>Report status to Tug operations center.<br>Perform TOI burn (main engine).<br>Coast, position and velocity update.<br>Determine parameters for midcourse correction.<br>Maneuver to required attitude for correction burn.<br>Report status to Tug operations center.<br>Perform course correction burn (APS).<br>Position and velocity update.<br>Report status to Tug operations center.<br>Coast operations. |
| 15.3 Payload Operational Orbit Injection Maneuvers | Provide all operational commands and monitor/control those Tug/payload parameters that are critical for mission success:<br>Attitude update.<br>Position and velocity update.<br>Compute orbit injection burn parameters.<br>Maneuver to required attitude for burn.<br>Verify subsystem ready for burn.<br>Report status to Tug operations center.<br>Perform OI burn (main engines).<br>Position and velocity update.<br>Coast operations. |
| 15.4 Deploy Payload | Provide all operational commands and monitor/control those Tug/payload parameters that are critical for mission success:<br>Maneuver to required attitude for payload separation.<br>Verify payload ready for release.<br>Uncouple Payload/Tug umbilicals. |

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Table 11. Avionics Tasks During Tug Flight, Cont'd

| MISSION PHASE | AVIONICS TASKS |
|---|---|
| 15.4 Deploy Payload (Cont'd) | Spin up payload (if necessary).<br>Separate Tug from payload (APS).<br>Activate payload for proper operations.<br>Despin Tug spin up device.<br>Report status to Tug operations center.<br>Coast operations. |
| 15.5 Payload Target Phasing Orbit Maneuvers for Rendezvous with Payload (Payload Retrieval Mission) | Provide all operational commands and monitor/control those Tug/payload parameters that are critical for mission success:<br>Attitude update.<br>Position and velocity update.<br>Compute phasing orbit injection parameters.<br>Maneuver to required attitude for burn.<br>Verify subsystems ready for burn.<br>Report status to Tug operations center.<br>Perform phasing orbit burn.<br>Coast operations.<br>Determine timing & parameters for midcourse correction.<br>Maneuver to required attitude for midcourse correction burn.<br>Report status to Tug operations center.<br>Perform midcourse correction burn.<br>Coast operations. (Target is ahead) |
| 15.6 Inject into Payload Target Rendezvous Orbit (Payload Retrieval Mission) | Provide all operational commands and monitor/control those Tug/payload parameters that are critical for mission success:<br>Attitude update<br>Positional velocity update<br>Compute rendezvous, circularization parameters<br>Verify subsystems ready<br>Report status to Tug operations center<br>Perform rendezvous orbit burn |
| 15.7 Rendezvous with Payload Target (Payload Retrieval Mission) | Provide all operational commands and monitor/control those Tug/payload parameters that are critical for mission success:<br>Attitude update<br>Activate rendezvous radar aids<br>Orient Tug for target radar acquisition & determine ranging data<br>Determine rendezvous burn parameters<br>Maneuver Tug to rendezvous burn attitude<br>Verify subsystems ready for burn<br>Report status to Tug Operations Center<br>Perform rendezvous burn<br>Coast operations<br>Activate and verify Tug Television<br>Activate & verify docking aids<br>Determine range and range rate |

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Table 11. Avionics Tasks During Tug Flight, Contd

| MISSION PHASE | AVIONICS TASKS |
|---|---|
| 15.8 Dock with Payload (Payload Retrieval Mission) | Provide all operational commands and monitor/control those Tug/payload parameters that are critical for mission success.<br>Translate to docking position<br>Monitor docking on TV<br>Stow PL antenna, etc.<br>Passivate Payload<br>Confirm payload ready for docking<br>Maneuver to docking attitude<br>Spin up docking mechanism (if necessary)<br>Close at contact velocity (APS)<br>Dock and attach payload<br>Despin docking mechanism<br>Switch payload to Tug power<br>Safe payload<br>Vent excess payload consummables<br>Verify payload ready for return<br>Report status to Tug operations center<br>Coast operations |
| 15.9 Inject into Return Transfer Orbit and Coast | Provide all operational commands and monitir/control those Tug/payload parameters that are critical for mission success:<br>Attitude update<br>Position & velocity update<br>Compute TOI burn parameters<br>Maneuver to required attitude for burn<br>Verify subsystems ready for burn<br>Report status to Tug operations center<br>Perform TOI burn (main engine)<br>Update state vector<br>Determine parameters for mid-course correction<br>Maneuver to required attitude for correction burn<br>Report status to Tug operations center<br>Perform course correction burn<br>Position and velocity update<br>Report status to Tug operations center<br>Coast operations |
| 15.10 Inject into Return Phasing Orbit | Provide all operational commands and monitor/control those Tug/payload parameters that are critical for mission success:<br>Attitude update<br>Position and velocity update<br>Compute phase orbit injection burn parameters<br>Maneuver to required attitude for POI burn<br>Verify subsystems ready for burn<br>Report status to Tug operations center<br>Coast operations |

## Table 11. Avionics Tasks During Tug Flight, Contd

| MISSION PHASE | AVIONICS TASKS |
|---|---|
| 15.11 Inject into Orbiter Rendezvous Orbit | Provide all operational commands and monitor/control those Tug/payload parameters that are critical for mission success:<br>Attitude update<br>Position and velocity update<br>Compute rendezvous orbit burn parameters<br>Maneuver to required attitude for ROI burn<br>Verify Tug subsystems ready for POI burn<br>Report status to Tug operations center<br>Perform ROI burn (main engine) 170 n. mi.<br>Position & velocity update<br>Stationkeep, radar lock-on<br>Report status to mission control<br>Coast operations |
| 15.12 Orbiter Rendezvous with Tug | Provide all operational commands and monitor/control those Tug/payload parameters that are critical for mission success:<br>Safe Tug<br>Disarm main propulsion system<br>Dump propellants<br>Attitude update<br>Position & velocity update<br>Ready Orbiter for rendezvous (O)<br>Establish communication between Tug & Orbiter<br>Establish Tug to Orbiter RF command<br>Verify Orbiter has Tug's attitude control<br>Maneuver Tug to rendezvous attitude<br>Stationkeep<br>Verify deployment adapter is ready to receive Tug (O)<br>Determine range and range rate (O)<br>Determine rendezvous intercept maneuver (O)<br>Compute burn parameters (O)<br>Maneuver Orbiter for proper burn (O)<br>Verify Orbiter readiness for burn (O)<br>Perform burn (O)<br>Coast, Hohmann transfer (O)<br>Corrections as necessary (O)<br>Verify safety status of Tug (O)<br>Orient Orbiter for final maneuvers (O)<br>Perform final burn maneuvers (O)<br>Stationkeep |



(O) = Orbiter Task